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Impact of Policy that Drives Low Carbon Technologies on Distribution Networks

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Transform Model Analysis and Support

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Impact of Policy that Drives Low Carbon Technologies on Distribution Networks

by

Manuel Castro, Laurence Elner and Mark Sprawson

Summary

The Department of Energy & Climate Change (DECC) has sought specialist advisory support from EA Technology to: (i) investigate the impacts posed by the integration of low carbon technologies (LCTs) in the electricity distribution infrastructure investment; and (ii) provide a framework that will contribute to the development of energy policy.

In order to address the questions raised by DECC in the Research Project Specification and in subsequent discussions during the project's scoping phase, EA Technology has developed detailed analyses to:

- Quantify the impact of LCTs on distribution network investment, identify its drivers and measure their respective impact.
- Quantify the impact of energy policy associated with the integration of LCTs on expenditure requirements for the development of Great Britain's (GB) distribution networks and to inform the development of Government policies.
- Investigate the impact of key factors (e.g. network investment strategies) on distribution network investment and policy development.

The key findings of the analyses performed by EA Technology are based on the LCTs' trajectories provided by DECC and can be summarised as follows:

- The overall expenditure requirements for LCT related distribution network investment[1] in the period 2015 – 2030 are mainly driven by the electrification of heating and transport sectors. Load technologies such as heat pumps and electric vehicles significantly increase the load on distribution networks. Heat Pumps are estimated to drive 60% of the overall distribution network expenditure related to LCTs whilst electric vehicles drive 38% under DECC's "High" trajectory for all LCTs.
- Generation technologies such as distributed solar photovoltaic and wind have low or no impact respectively, on the overall expenditure requirements for distribution network investment (i.e. total network expenditure for the period 2015 – 2030) when modelled as having equal probability of connecting at various points along a circuit. These LCTs are observed to contribute to offset load growth imposed by the electrification of heating and transport sectors. Distributed solar photovoltaic are estimated to drive 2% of the overall distribution network expenditure. It should be noted that this refers only to generation connected at 33kV and below and only costs that are socialised through DUoS (i.e. not costs associated with large generators that are borne by developers and can be significant).

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[1] All prices based on 2013/14 figures.

- Nevertheless, the investment profile for distribution network assets is triggered by different LCTs over time. In the short term, distribution network investment is observed to be driven by distributed solar photovoltaic and distributed wind as the presence of heat pumps and electric vehicles in the network are relatively low. In the long term, the electrification of the heating and transport sectors are estimated to trigger most of the investment requirements for distribution network development.
- The overall network expenditure driven by LCT policy “in place or sufficiently planned” is relatively close to that of a no-policy case (i.e. “Baseline”). Thus, policy “in place or sufficiently planned” initiates the transition process to a low carbon economy of the future, incentivising the deployment of LCTs amongst other measures, without increasing significantly the overall expenditure requirements for distribution network development over the period 2015 – 2030.
- On average over the period 2015 – 2030, LCT policy “in place or sufficiently planned” is estimated to increase the distribution network charges by 3 pence compared to the “Baseline” trajectory. Specifically, the Distribution network Use of System charges (DUoS) increase from £0.16/MWh in the “Baseline” trajectory to £0.19/MWh in the policy “in place or sufficiently planned”. This excludes the impact of efficiency measures. Simplified analysis of DECC’s 2013 Updated Energy and Emission Projections (UEP) for indicative purposes, shows that energy efficiency policies (those in place or sufficiently planned) are likely to more than offset this cost.
- Electricity Market Reform (EMR) and small scale Feed-in Tariffs (FiTs) policy measures have a relatively low impact on expenditure for distribution network investment as the contribution of distributed solar photovoltaic and wind power technologies often has a positive, rather than a negative, impact on network capacity, provided that sufficient demand levels persist to absorb this generation capacity, meaning that its contribution towards constraining distribution network headroom is limited.
- The range of impact of EMR and FiTs policy measures on the expenditure required for investment in distribution network assets is relatively narrow. The overall distribution network expenditure ranges from £0.9bn in the “Low” trajectory to £1bn in the “High” trajectory over the period 2015 – 2030.
- Smart distribution network investment strategies (i.e. incremental and top-down) that use innovative solutions in conjunction with conventional reinforcement options appear to be more cost effective than using solely conventional solutions (i.e. business as usual).
- Incentivising the deployment of hybrid heat pumps significantly reduces the overall expenditure requirements for distribution network investment. The overall distribution network expenditure ranges from £3.3bn with hybrid heat pumps to £6.2bn with non-hybrid heat pumps over the period 2015 – 2030 under DECC’s high trajectories.
- The introduction of energy efficiency measures together with a relatively mild uptake of LCTs over the period 2015 – 2020, results in reduced levels of demand which in turn decrease network losses. In the period 2020 – 2030, the rise in the uptake of LCTs and economic growth results in higher demand for energy and consequently network losses. Over the period 2015 – 2030, the effects that energy efficiency measures may have on electricity demand reduction are outweighed by those driven by the increasing presence of LCTs resulting in higher costs attributable to distribution network losses.
- LCTs are estimated to contribute to a slight increase in Distribution Use of System charges (i.e. DUoS). On average (i.e. period 2015 – 2030), distribution networks charges were found to range from £0.18/MWh in the “Low” to £0.36/MWh in the “High” Trajectory. This excludes any offsetting impact from energy efficiency measures.
- The relationship between distribution network investment expenditure and the uptake level of LCTs has been expressed through the metric “Currency per MW of LCT”. Over the period of 2015 – 2030, the distribution network expenditure ranges on average, from £5.1k/MW of LCT connected in the “Low” policy trajectory to £7.5k/MW of LCT connected in the “High” policy trajectory.

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1 Introduction

1.1 Context

Government low carbon and energy efficiency policies could bring savings to and incur costs on electricity distribution networks. Policy that drives energy efficiency is likely to decrease the loads and thus avoid/defer network reinforcement costs. Policies which drive load technologies such as heat pumps and electric vehicles are likely to result in network reinforcement costs in order to accommodate larger loads. Policy that increases the connection of renewable generation embedded on the distribution network could also result in network reinforcement costs in order to transfer supply to load consumption areas, although as this report shows could also offset some of the reinforcement necessary for load technologies.

A significant and steady increase in DUoS charges has been seen throughout the current distribution price control period (DPCR5)[2]. This has been largely driven by the need to replace and maintain ageing network and not significantly by Government's low carbon policy. This is analogous with the initial period analysed in the Transform Model in this report and also with analysis of RIIO-ED1 business plans which also show that distribution reinforcement costs across the short term are not driven by government low carbon ambitions. However, it is important to DECC to understand how this will change as deployment of low carbon technologies increases over time.

DECC has sought specialist advisory support from EA Technology to: (i) investigate the impacts posed by the integration of LCTs in the electricity distribution infrastructure investment; and (ii) comprehend the impact of these technologies in the development of energy policy.

Specifically, the project focusses on the impact that specific low carbon technologies (LCTs) connected to the distribution network (i.e. Heat Pumps (HPs), Electric Vehicles (EVs), Solar Photovoltaic (PV) and Wind) and that specific Government's energy policies (i.e. those "already in place or planned to a sufficient degree of detail", Electricity Market Reform (EMR) and Feed-in Tariffs (FiTs)) may cause on electricity distribution network investment.

EA Technology's assessments and analyses have been based on the detailed application of its proprietary Transform Model developed for activities undertaken in the Smart Grid Forum[3], co-chaired by DECC and Ofgem. The Transform Model has been extensively used by Distribution Network Operators (DNOs) as a network investment and planning tool to support the development of their business plans for RIIO-ED1, which have been submitted to and reviewed by Ofgem.

1.2 Questions, aims and objectives

In order to comprehensively understand network investment costs, charging mechanisms, policy and other techno-economic impacts associated with the integration of LCTs in GB's distribution networks, this work is divided into two main questions[4] (MQ) and areas of analysis:

- **MQ1.** What are the distribution network investment and Use of System charges impacts disaggregated by individual technologies connected to the distribution network (these are likely to be Solar PV, EVs, HPs and Wind)?

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[2] ENA, 2014. "Distribution Use of System Charges", Energy Networks Association, Archives, 2014. http://www.energynetworks.org/electricity/regulation/duos-charges/distribution-use-of-system-charges/

[3] DECC and Ofgem Smart Grid Forum. https://www.ofgem.gov.uk/electricity/distribution-networks/forums-seminars-and-working-groups/decc-and-ofgem-smart-grid-forum

[4] DECC's Research Project Specification: Policy Impact on Networks Research.

This question details the application of the Transform Model to DECC's trajectories for the relevant technologies to quantify their costs and benefits in terms of distribution network investment and charging by identifying respective drivers and measuring their impact.

The Transform Model quantifies the required levels of expenditure for investment in distribution network assets to enable the cost-efficient and secure integration of LCTs. Network investments are then disaggregated between thermal related expenditure (i.e. primarily driven by changes in load, such as EVs, HPs, etc.) and voltage related expenditure (i.e. primarily driven by changes in generation, such as PV, Wind, etc.). This approach permits the identification of the main drivers for network investment and measuring their impact as the magnitude of expenditure per driver is quantified. The identified drivers (i.e. thermal and voltage) can be further disaggregated into each of the LCTs considered to quantify their individual contribution to the overall distribution network expenditure.

- **MQ2.** What are the distribution network investment and Use of System charge impacts disaggregated by policies? In particular, what is the impact of policies "already in place or planned to a sufficient degree of detail" and the impact of EMR and FiTs policy measures (in particular of distributed solar photovoltaic and wind generation)?

This question deploys DECC's policies under investigation (i.e. EMR and FiTs) into the Transform Model to quantify and assess associated costs and benefits in terms of distribution network investment and charging.

DECC's Research Project Specification extends the aforementioned MQs to introduce a list of specific questions (SQ) as follows:

- **SQ1.** How could smart technologies reduce the impact of each of these technologies?
- **SQ2.** How does the impact of HPs vary with different technology types?
- **SQ3.** What is the impact of these technologies on network losses?
- **SQ4.** What is the impact per unit of each technology and under what assumptions could such off-model relationships for each of these technologies be used? Are there any broader per unit costs that could be applied to groupings of technologies?
- **SQ5.** Under DNOs' RIIO-ED1 Business Plans how much expenditure is due to reinforcement of the grid cause by Low Carbon Technology deployment? How much expenditure is driven by policy?

In the above list of questions, following DECC's interpretation, "impact" refers primarily to distribution network investment costs and Use of System charges.

In accordance with DECC's Research Project Specification and subsequent scoping discussions, the overall scope of the project involves the detailed application of EA Technology's Transform Model to evaluate the impact of electricity distribution infrastructure investment and charging in the future low carbon energy system and on-going energy policy developments. It is important to note that this report focuses on distribution network reinforcement costs, so wider system costs of LCT deployment, such as Balancing Costs, are not captured in this analysis. This analysis also does not take account of network operating costs and costs associated with the replacement of ageing assets

The quantitative assessments to address DECC's questions are based on individual trajectories for the relevant LCTs. These individual trajectories are further combined to form specific policy scenarios. The various trajectories for the deployment of LCTs and the policy scenarios have been developed by DECC and provided to EA Technology for the development of this work.

1.3 Approach to work

In order to address the project's questions as stated in DECC's Research Project Specification and according to the scoping discussions, EA Technology's GB version of the Transform Model has been applied to quantify and assess the impacts posed by the integration of LCTs in the electricity distribution infrastructure investment. This drives out an understanding of the contribution that these technologies can make towards meeting carbon reduction targets and renewable energy generation obligations and to inform the development of Government policies. As a result, the following main assessments have been developed:

- LCT driven distribution network investment. It quantifies the impact of LCTs on distribution network investment, identifies its drivers and measures their respective impact.
- Policy driven distribution network investment. It quantifies the impact of energy policy associated with the integration of LCTs on expenditure requirements for distribution network investment and to inform the development of Government policies.
- Sensitivity and further analyses. It investigates the impact of specific key factors on distribution network investment and policy development.

1.4 Structure of the report

This report details the approach, analyses and key findings of the work developed by EA Technology as a response to the project proposal commissioned by DECC. The remainder of this report is structured as follows:

- Section 2 describes the details of the methodology developed by EA Technology to address DECC's questions.
- Section 3 briefly introduces DECC's trajectories for the uptake of LCTs.
- Section 4 investigates the impact of LCTs on distribution network investment.
- Section 5 explores the impact of energy policy associated with the integration of LCTs on distribution network investment.
- Section 6 assesses the impact of specific key factors on distribution network investment and policy development.
- Section 7 summarises the key findings of the work.

2 Methodology

This section provides details of the methodological approach followed by EA Technology to address the work questions specified in DECC's Research Project Specification. Figure 1 depicts an overview of the approach.

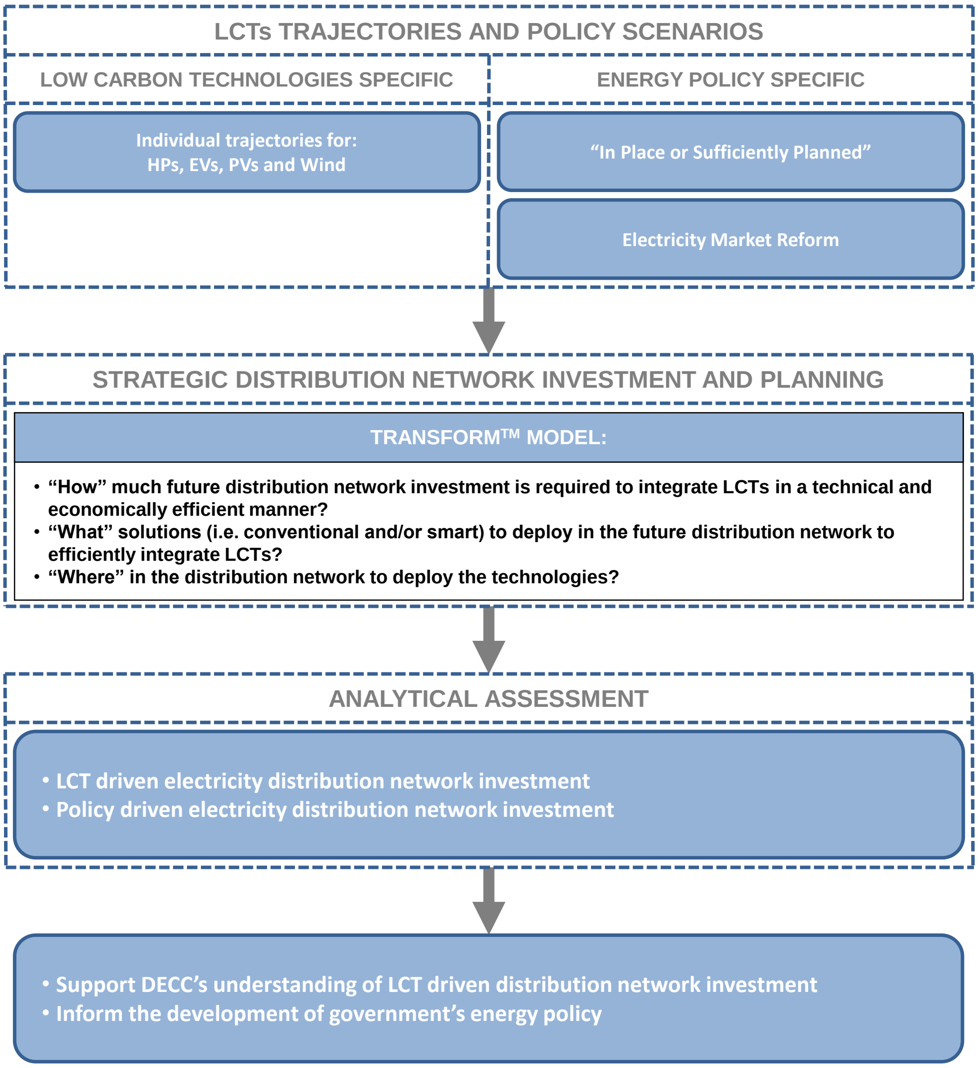

Figure 1: Overview of the approach

2.1 Main trajectories and scenarios

DECC has provided a set of trajectories (i.e. "Baseline", "Low", "Central" and "High") to reflect present and future uptake levels of LCT (i.e. HP, EV, PV and W). The "Low", "Central" and "High" trajectories are then combined to form the scenarios to be modelled. Some of these scenarios are representative of specific policy cases (i.e. policy "in place or sufficiently planned" and "EMR and FiTs") whilst the "Baseline" trajectory is used to represent no-policy cases. The trajectories reflect varying assumptions for the on-going levels of policy support, barriers to consumer uptakes and assumptions regarding technology improvements and commercialisation. The trajectories provided cover the period from 2012 to 2030. Section 3 introduces DECC's trajectories in greater detail.

2.2 Strategic distribution network investment and planning

The strategic distribution network investment and planning assessment is performed through the application of EA Technology's Transform Model to a detailed representation of the electricity distribution network in GB.

Transform Model is a techno-economic tool to assess investment decisions in electricity distribution infrastructure that enable the cost-efficient and secure integration of LCTs in the future low carbon energy system. Thus, the Transform Model[5] provides an in-depth understanding of:

- "How" much future distribution network investment is required to integrate LCTs in a technical and economically efficient manner?
- "What" solutions (i.e. conventional and/or smart) to deploy in the future distribution network to efficiently integrate LCTs?
- "Where" in the distribution network to deploy the technologies?

In this project, the Transform Model is used in the context of development of energy policy to inform DECC on the impact of the policies under analysis in distribution network investment in a future low carbon energy system. The application of the Transform Model to DECC's policy scenarios will enable DECC to understand the impact of policy drivers, find potential policy gaps and respective drivers, devise solutions and test policy performance.

2.3 Analytical assessment

The analytical assessment is aimed at supporting DECC's understanding of the impacts posed by the integration of LCTs in the electricity distribution infrastructure investment and of the contribution that LCTs can make towards meeting carbon reduction targets and renewable energy generation obligations and to inform the development of Government policies. To this objective, the analytical assessment has: (i) quantified the impact of LCTs on distribution network investment, identified and measured its drivers; and (ii) evaluated the impact of energy policy associated with the integration of LCTs on expenditure requirements for distribution network investment.

2.4 Key modelling modifications

EA Technology's Transform Model has been modified, where appropriate, in order to address specific questions detailed by DECC in the Research Project Specification. In this respect, the key modelling modifications can be divided into those associated with trajectories and with low carbon technologies.

2.4.1 Trajectories

Transform Model version 4.0.2 has been used to perform the quantitative assessments and analyses of this project. Transform published scenarios have consequently been updated to account for DECC's proposals on the uptake levels of LCTs. It has been observed that the uptake levels of LCTs are generally higher in DECC's trajectories when compared to Transform Model published scenarios. Section 3 introduces the trajectories used in this project in greater detail.

The Transform Model employs a forward look approach to network investment such that it satisfies distribution network headroom requirements at a given point in time (i.e. n, where n is the number of years forward). It has been agreed with DECC, during the scoping phase of the project, that the number of years forward to be used in the analyses would be equal to five in accordance with common practice amongst DNOs and Ofgem for business planning purposes.

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[5] EA Technology et al., Aug 2012. "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks". DECC and Ofgem Smart Grid Forum.

Since the Transform Model has been set, in this project, to resolve network headroom constraints for a minimum of five years from the time the headroom trigger is reached, an extra five years' worth of data is required (i.e. 2031 – 2035) to quantify investment in the period 2026 – 2030. In this respect, EA Technology has extrapolated DECC's data sets to represent the uptake levels of LCT's during the forward looking period.

The approach developed to extend DECC's data for the period 2031 to 2035 relies on a simple extrapolation that uses information contained in the data sets provided by DECC. Thus, for each LCT, the rate of growth is determined from the last two years of data, i.e. 2029 and 2030. This growth is then assumed to be present on every year from 2031 to 2035 for the LCT under consideration.

It should be noted that this approach is applied to all LCTs. The growth rate may change between different LCTs as it is dependent on the information contained in the original data sets provided by DECC.

Nonetheless, it is noted that the approach was slightly modified for the extrapolation of the "Low" trajectory of solar PV. The growth rate for solar PV between the years 2029 and 2030 was observed to be relatively high and driven by large PV installations (i.e. greater than 5MW) since the growth of smaller PV installations (i.e. smaller than 5MW) was observed to saturate around the year 2020. This behaviour results in the "Low" trajectory crossing-over the "Central" and "High" trajectories in the year 2036 and 2047, respectively. To overcome this, it has been assumed that the "Low" trajectory will grow at a similar rate to that observed in "Central" and "High" trajectories (these trajectories both have a similar growth rate of uptake). It has also been observed from DECC's data sets, that the "Central" and "High" trajectories reach a saturation point in the year 2028 and 2029 respectively. Consequently, it has been assumed for the "Low" trajectory to reach the same saturation point by 2031, thus preserving DECC's data set (to 2030) intact.

Appendix 1 presents the three trajectories (i.e. "Low", "Central" and "High") for each LCT over the period of 2012 – 2035.

2.4.2 Low carbon technologies

Previous modelling work carried out for the DECC Heat Strategy[6] showed that for some scenarios hybrid heat pumps could play an important role in the decarbonisation of heat out to 2050. In this respect, the work for the Heat Strategy suggested that around 90% of the overall heat pump installations might be hybrid (i.e. gas and electric) with the remaining 10% being non-hybrid (i.e. fully electric with or without storage capability).

Accordingly, the Transform Model has been set to target the deployment of hybrid heat pumps into on-gas grids and of non-hybrid heat pumps into off-gas grids enabling DECC to understand the potential implications of the deployment of hybrid heat pumps on the cost requirements for the development of electricity distribution networks. The impact of the deployment of non-hybrid heat pumps is presented in section 6.2. It should be noted that the report does not consider the difference in capital and operating costs from deploying hybrid heat pumps, nor the implications for the gas-grid.

The Transform Model uses its default heat pump consumption profile to represent the non-hybrid heat pumps and has been enhanced to include representative consumption profile for hybrid heat pumps. Figure 2 introduces the consumption profile for non-hybrid and hybrid heat pumps used in the Transform Model.

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[6] DEEC, 2013. "The Future of Heating: Meeting the Challenge", Department of Energy & Climate Change, 26 Mar 2013. https://www.gov.uk/government/publications/the-future-of-heating-meeting-the-challenge

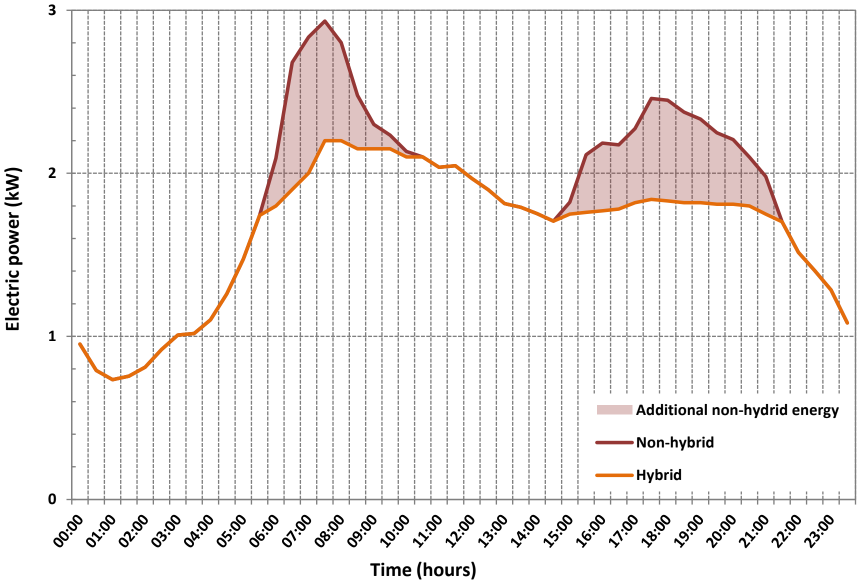

Figure 2: Daily winter consumption profile for non-hybrid and hybrid heat pumps

Hybrid heat pumps use gas to provide heat to consumers during periods of coincidence of low outdoor temperatures and high energy demand consumption (i.e. peak demand periods). As a result of this operational behaviour, Figure 2 shows that hybrid heat pumps have lower peak demand and energy consumption compared to non-hybrid heat pumps as they burn gas to provide heat during peak demand periods.

The consumption profile for hybrid heat pumps has been derived by EA Technology based on real data observations and information from the manufacturers. As a consequence, Figure 3 shows the relationship between the size of an electric domestic heat pump and respective annual heat delivered.

The derivation process of Figure 3 uses the Annual Performance Method[7] to convert a design-day heat load into an annual space-heating energy consumption value. This value is then split into daily totals using a degree-day analysis. The method has previously been used for the evaluation of micro CHP projects for several clients and has been subsequently adapted to heat pump performance for use in the EA Technology response to DECC's consultation on the future of low carbon heating in the UK[8][9].

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[7] BRE, 2008. "Method to Evaluate the Annual Energy Performance of Micro-Cogeneration Heating Systems in Dwellings", Report to Defra CEEH, 9 Oct 2008.

[8] DECC, 2012. "The Future of Heating: A Strategic Framework for Low Carbon Heating in the UK", Department of Energy & Climate Change, 29 Mar 2012.

[9] EA Technology Ltd, 2012. Response to "Strategic Framework for Low Carbon Heating in the UK", May 2012.

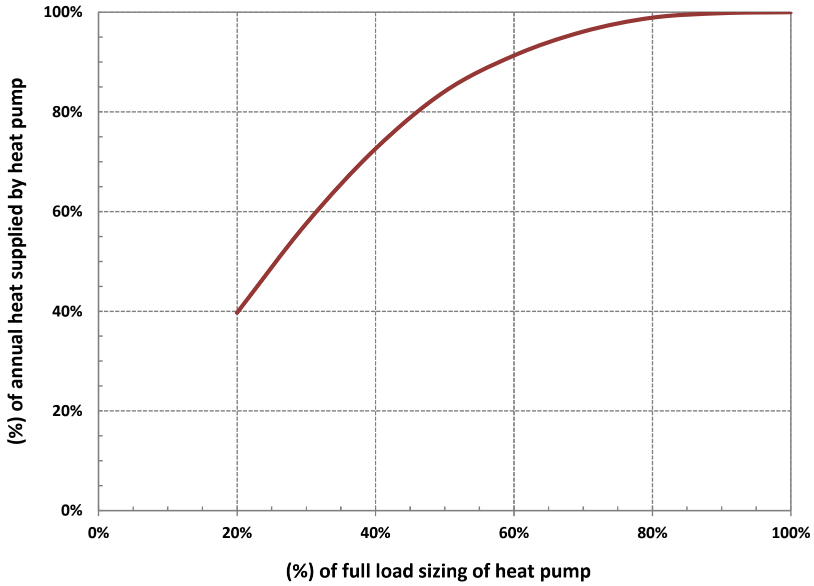

Figure 3: Ability of under-sized heat pumps to supply heating demand

For instance, Figure 3 indicates that an electric domestic heat pump that has a power rating of 60% of its original size is capable of meeting 90% of the annual heat requirements of a domestic dwelling. Alternatively, this can be interpreted as being a hybrid heat pump with a 40% reduced power rating where the missing 10% of the annual heat requirements are met by gas.

In the development of the consumption profile for the hybrid heat pump a conservative approach has been taken to assume hybrid heat pumps have a 25% peak power lower than the non-hybrid heat pumps. As a result, 98% of the annual heating requirements of the domestic household are met through electricity and 2% are supplied by gas. In terms of daily energy consumption at times of winter peak, it implies that hybrid heat pumps present 5% lower energy requirements than non-hybrid heat pumps. This conservative approach ensures that the potential benefits of using hybrid as opposed to conventional heat pumps are not overstated. Further work would be required to validate the actual performance of hybrid against conventional heat pumps in identical buildings.

2.4.3 Network investment and planning impacts

The aforementioned modelling modifications are expected to impact the levels of expenditure for distribution network investment in two key ways:

- Under greater uptake levels of LCTs, distribution networks are expected to observe increased peaks and demand for energy resulting in higher requirements for network investment when comparing the impact of DECC’s trajectories against Transform Model version 4.0.2 published scenarios.
- Under significant deployment of hybrid heat pumps, distribution networks are expected to observe reduced peaks and demand for energy leading to lower requirements for network investment compared to the presence of non-hybrid heat pumps only.

2.5 Key modelling assumptions

The key assumptions for the assessments to be performed under this project are summarised as follows:

- LCT expenditure ratios will be determined in an initial analysis to capture the expenditure due to different LCTs. These ratios will be carried forward into further analysis and it will be assumed that they will not deviate beyond the range stipulated from this initial analysis.

- The GB model default settings (which have been collectively agreed between all DNO's) are valid and applicable for Transform Model simulation runs, unless stated otherwise in the final report.
- The Transform Model's default unit sizes will be used as part of the analysis, unless stated otherwise in the final report.
- It is assumed that the GB model (or licence area scaled GB model where necessary) is a representative sample containing key networks identified to be typical of GB wide variations.
- In order to analyse Hybrid/Fully electric HPs that are primarily situated on 'Off gas grid connections', it will be assumed that these off gas grid connections reside on stipulated networks (likely; LV9 – Rural village (overhead construction), LV10 – Rural village (underground construction), LV11 – Rural farmsteads small holdings).
- Output results are defined by the Transform Model's calendar year rather than financial years. For example, RIIO-ED1 period is covered by 2015 – 2022 calendar years as opposed to 2016 – 2023 financial years.

3 Trajectories for low carbon technologies

DECC has developed a set of trajectories aimed at: (i) understanding the impacts posed by the integration of LCTs on electricity distribution infrastructure investment; (ii) understanding the contribution that these technologies can make towards meeting carbon reduction targets and renewable energy generation obligations; and (iii) informing the development of Government policies.

DECC's trajectories are representative of present and future uptake levels of LCTs considered in the analyses (i.e. HP, EV, PV and Wind). Subsequently, the individual trajectories are combined to form specific scenarios. DECC has provided three trajectories (i.e. "Low", "Central" and "High") for the uptake levels of each LCT, which can be used to represent specific policy cases (i.e. policy "in place or sufficiently planned" and "EMR and FiTs") and one trajectory (i.e. "Baseline") to characterise no-policy cases. The trajectories reflect varying assumptions for the on-going levels of policy support, barriers to consumer uptake and assumptions regarding technology improvements and commercialisation. The trajectories provided cover the period from 2012 to 2030.

The following subsections briefly introduce DECC's trajectories for the individual LCTs, that have been identified to have the greatest impact on the development and operation of distribution networks and are used as inputs for the analyses performed in the Transform Model.

3.1 Heat pumps

The heat pump trajectories came from the modelling work carried out for the Fourth Carbon Budget and are consistent with the forecasts in the Government's Carbon Plan[10]. However, DECC has slightly revised these trajectories to explore the impact of potential policy options.

Figure 4 presents DECC's trajectories for the uptake of heat pumps in GB expressed as the number of heat pumps in operation in the building stock. It can be observed that the trajectories are characterised by similar uptake levels up to 2020. Beyond this year, the uptake levels of "Low" trajectory remain practically constant until the year 2030 whilst "Central" and "High" trajectories significantly diverge from "Low" to reflect approximately a tenfold increase in the year 2030. The electrification of the heating sector leads to a substantial deployment of heat pumps which in turn is expected to affect the investment requirements in distribution network assets.

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[10] HM Government, 2011. "The Carbon Plan: Delivering our Low Carbon Future", HM Government, Dec 2011. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47613/3702-the-carbon-plan-delivering-our-low-carbon-future.pdf

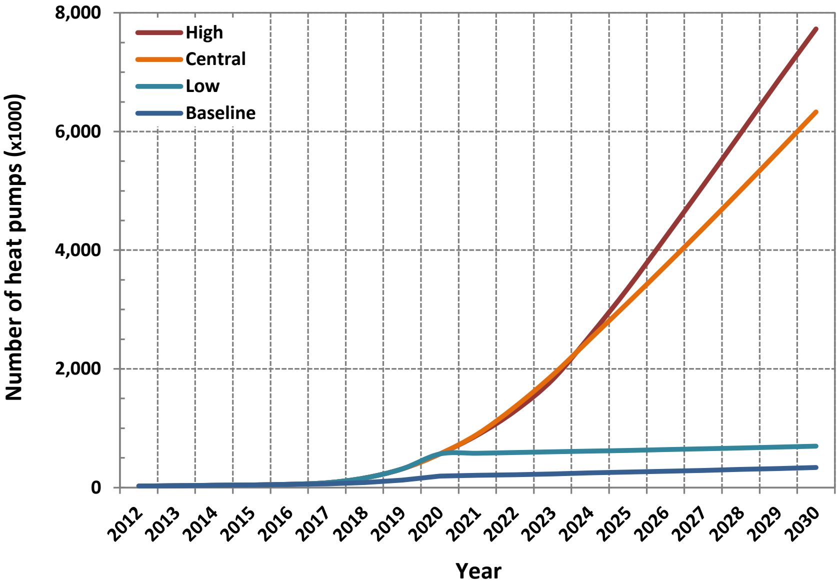

Figure 4: DECC's trajectories for the uptake of heat pumps in GB

DECC has provided the heat pump uptake trajectories disaggregated by residential, business and public sectors with and without storage capability. It is observed that in all trajectories the uptake in the residential sector dominates that of the business and public sectors together.

Moreover, the trajectories used in this project favour the deployment of hybrid heat pumps for domestic consumers such that 90% of the overall domestic heat pump installations are hybrid (i.e. gas and electric) and 10% are non-hybrid (i.e. electric with or without storage capability).

3.2 Electric vehicles

The electric vehicle uptake assumptions were developed for the Smart Grids Forum to be consistent with various options for meeting the Fourth Carbon Budget. The analysis is generally "top-down", reflecting levels of ultra-low emission vehicle (ULEV) uptake consistent with certain 2030 new car (or van) CO_2 targets, although for the low scenario a "bottom-up" assessment is used initially. For cars these reflect a 70g, 60g or 50g target for the low, central and high case respectively. These ULEVs would not necessarily be plug-in EVs, as the approach to date has been technology neutral, but the assumption for this modelling is that this would be the case. To produce a Business as Usual scenario, the Department for Transport (DfT) has produced stock forecasts based on ULEV uptake remaining low.

Figure 5 introduces the DfT's trajectories for the uptake of electric vehicles in GB expressed as the number of on-road vehicles. It can be seen the different trajectories start to significantly diverge towards the end of 2015 – 2020 period. In this sense, the number of on-road vehicles in the year 2030 ranges from 3 million in the "Low" trajectory to 10 million in the "High" trajectory. This significant uptake of electricity vehicles is likely to have a material impact in the future expenditure required for distribution network assets.

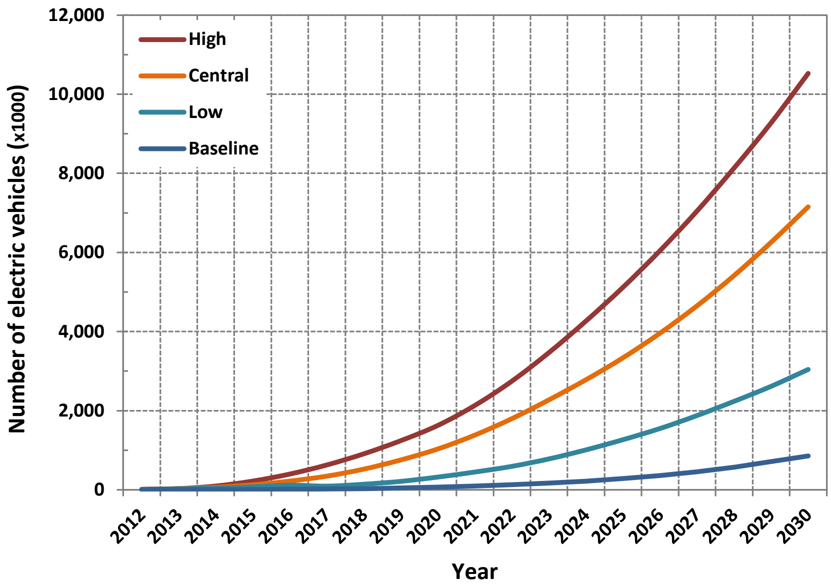

Figure 5: DfT's trajectories for the uptake of electric vehicles in GB

DfT has provided the electric vehicles uptake trajectories disaggregated by the type of charging, i.e. fast and slow.

3.3 Solar photovoltaic

The trajectories for distributed generation are consistent with the EMR Final Delivery Plan[11]. The "Central" deployment of distributed solar photovoltaic is consistent with "Scenario 1[12]", and DECC's "Central" FITs estimates. The Low and High trajectories are consistent with the high and low technology costs respectively in the Final Delivery Plan for large scale solar and with DECC's "Low" and "High" FITs estimates. The total solar photovoltaic ranges from 7GW to 18GW for the year 2020.

Figure 6 details DECC's trajectories for the uptake of solar photovoltaic in GB expressed as the aggregated installed capacity of the various installations. The "Low" trajectory considers the current levels of solar photovoltaic and then projects a low level of future growth. In contrast, "Central" and "High" trajectories present considerable higher future growth levels so that in the year 2030 the installed capacity of solar PV is 1.5 and 2 times higher than that of the "Low" trajectory respectively. The increasing deployment of solar PV installations in distribution networks can potentially impact investment requirements in network assets as this form of distributed generation may support offsetting part of load consumption needs. In other words, in the short term if demand remains relatively low, there may be a small level of impact on network expenditure driven by levels of small scale distributed generation (in this case solar PV). However, in the longer term, it is more likely that solar PV export supports the increased demand meaning that network expenditure is offset.

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[11] DECC, 2013. "Electricity Market Reform Delivery Plan", Department of Energy & Climate Change, 19 Dec. 2013. https://www.gov.uk/government/publications/electricity-market-reform-delivery-plan

[12] Scenario 1 in the EMR Delivery Plan spends around £7bn in 2020/21 and achieves around 33% renewable electricity in 2020. The scenario assumes maximum Strike Prices for renewable technologies at the levels as set out in the December Delivery Plan. Technologies affected by constrained allocation would be likely to see their actual Strike Price set at a lower value than the maximum. This has been captured within the modelling.

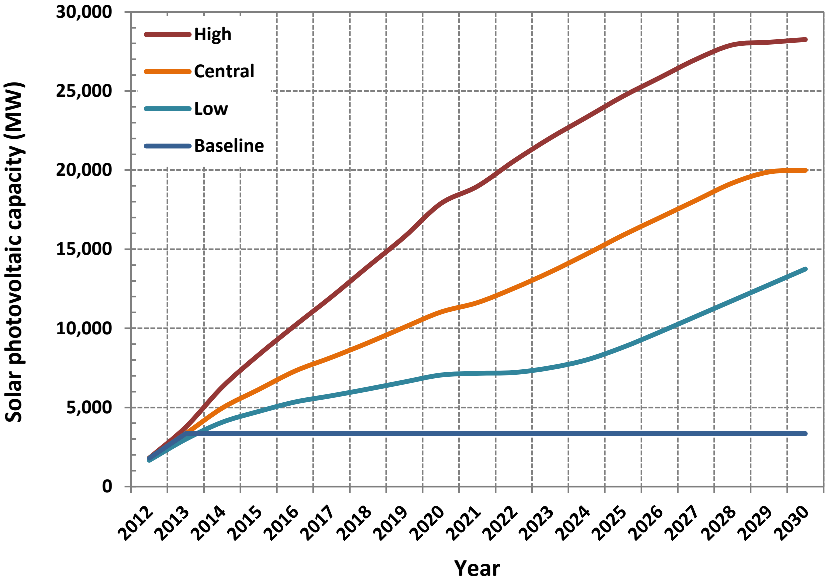


Figure 6: DECC's trajectories for the uptake of solar photovoltaic in GB

The trajectories for the uptake levels of distributed solar photovoltaic have been further disaggregated into the different voltage levels to which they connect in the distribution network. The Transform Model performs this disaggregation process relative to the size of the LCT's uptake level. The apportionment factors used in the disaggregation process has been derived from information received from the DNOs. Appendix 2 provides the trajectories for the uptake of distributed solar photovoltaic generation per voltage level of the distribution network.

3.4 Wind

The trajectories for distributed generation are consistent with the EMR Final Delivery Plan. The "Central" deployment of distributed wind generation is consistent with "Scenario 1". The "Low" and "High trajectories are consistent with the "High" and "Low" technology costs respectively in the Final Delivery Plan. The onshore wind range for 2020 is 11.6-14.2GW. The onshore wind ranges from 11.6GW to 14.2GW for the year 2020. This has been represented in the Transform Model in line with the methodology previously used for Smart Grid Forum Work Stream 3, whereby generation was apportioned to different voltage levels depending on its maximum export capability.

Figure 7 details DECC's trajectories for the uptake of distributed wind generation in GB expressed as installed capacity. The three trajectories for this technology present similar rates of future growth, however the uptake levels of each trajectory are different. It can be seen that the uptake levels of distributed wind generation are broadly constant throughout the period 2020 – 2030. Thus, over the 2020 – 2030 decade, the installed capacity of distributed wind is projected to grow 10% from the "Low" to "Central" trajectories and 12% from the "Central" to "High" trajectories. The integration of higher levels of distributed wind power in distribution networks can potentially have a measurable impact on the future network investment requirements as it may support offsetting load growth, for instance driven by other LCTs, as previously described for small scale generators.

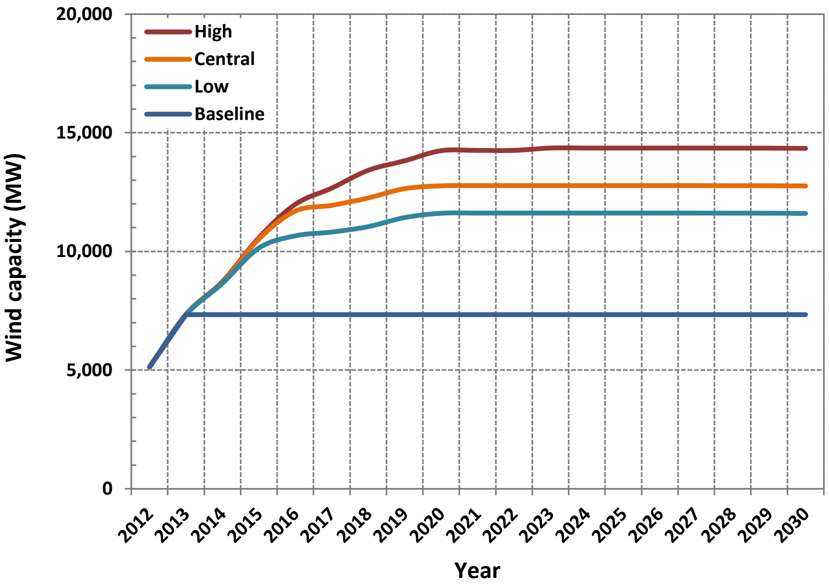


Figure 7: DECC's trajectories for the uptake of wind power in GB

The trajectories for the uptake levels of distributed wind generation have been further disaggregated into the different voltage levels to which they connect in the distribution network and are provided in Appendix 2.

4 LCT driven distribution network investment

This section details the application of the Transform Model to DECC's trajectories to quantify the impact of LCTs on distribution network investment, to identify its drivers and to measure their respective impact.

The Transform Model quantifies the required levels of expenditure for investment in distribution network assets to enable the cost-efficient and secure integration of LCTs. Network investments are then disaggregated between thermal related expenditure (i.e. primarily driven by changes in load, such as EVs, HPs, etc.) and voltage related expenditure (i.e. primarily driven by changes in generation, such as PV, Wind, etc.). This approach permits the identification of the main drivers for network investment as well as measuring their impact as the magnitude of expenditure per driver is quantified. The identified drivers can be further disaggregated into each of the LCTs considered to quantify their individual contribution to the overall distribution network expenditure.

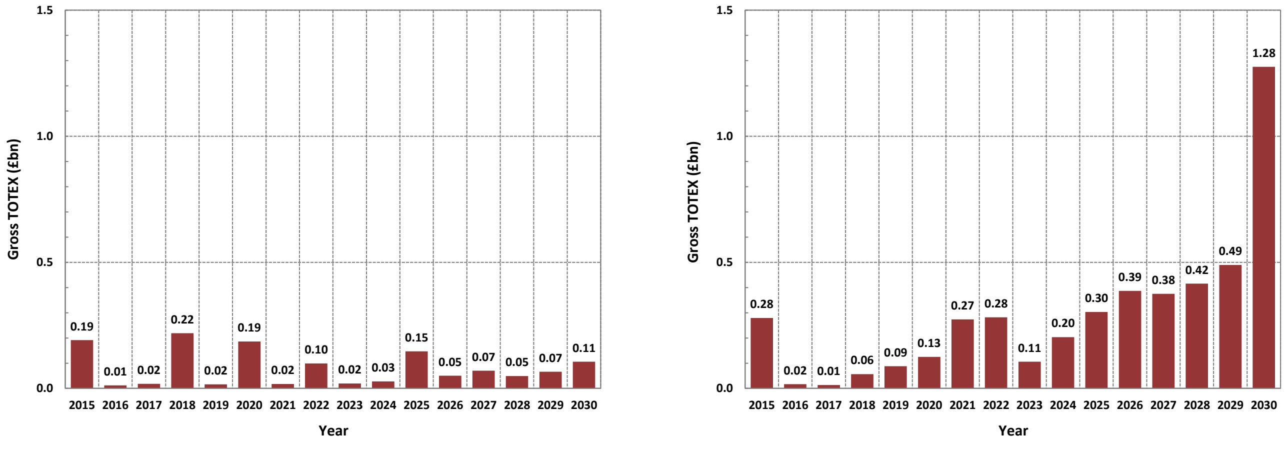
The trajectories (i.e. "Low", "Central" and "High") characterising the uptake levels of each LCT, (i.e. HP, EV, PV and Wind) have been combined in a specific manner to perform the analyses presented in section 4. Table 1 presents an overview of the main trajectory combinations considered in this section. It is noted that other combinations were considered where appropriate to quality assure some of the analyses undertaken in the report.

Table 1: Main combinations of LCT trajectories for the analyses performed in section 4

Report section	Analysis	Heat pumps	Electric vehicles	Solar photovoltaic	Wind
4 LCT driven distribution network investment	4.3 Contribution of LCTs to distribution network investment	High	High	High	High
		Baseline	High	High	High
		High	Baseline	High	High
		High	High	Baseline	High
		High	High	High	Baseline

4.1 Distribution network investment

The Transform Model has been applied to DECC's "Low" and "High" trajectories to quantify the impact of LCTs on distribution network investment. Figure 8 presents the levels of expenditure for distribution network investment under the "Low" and "High" policy trajectories for the future uptake of LCTs.



(a) "Low" trajectory **(b) "High" trajectory**

Figure 8: Distribution network investment expenditure for "Low" and "High" trajectory

For the analysis of this section, the “High” policy trajectory has been considered for the uptake levels of LCTs to evaluate expenditure requirements for distribution network investment as it drives the most substantial levels of network investment and therefore enables a better understanding of the potential combined impacts of LCTs. In contrast, using the “Low” trajectory for this analysis may not entirely provide a good understanding of some of the combined effects of LCTs (i.e. load/generation – act/counteract) that trigger network investment due to magnitude of scales.

It is observed in Figure 8 that investment in network assets is required year-on-year over the period of analysis. Network investment evolves in cycles driven by the growth of LCTs in the network and the deployment of a mixture of conventional and smart network solutions to mitigate network integration challenges. The magnitude of the total discounted expenditure (i.e. discounted TOTEX based on a discount rate of 3.5%, in line with the standard social discount rate used in GB) for the period is estimated to be £3.3bn (alternatively, £4.7bn gross (i.e. undiscounted) TOTEX).

It can also be seen in Figure 8 that distribution network expenditure in 2030 constitutes 27% of the gross expenditure over the period. In fact, extending the period of analysis, it is observed that network investment is deferred to beyond 2030 (i.e. it is deferred by approximately 15 years), as the magnitude of the network expenditure to 2030 is significantly lower than that registered beyond 2030. Incentivising the deployment of hybrid heat pumps has an important impact on the behaviour of the observed distribution network expenditure. Hybrid heat pumps tend to use gas during periods of coincidence of low outdoor temperature and peak demand. This operating pattern reduces peak demand and energy consumption leading to network investment deferral as the network is able to accommodate higher uptake levels of LCTs up to 2030.

In order to provide an insight on the rapid growth in distribution network expenditure observed in the year 2030, the network expenditure requirements have been disaggregated by the individual representative distribution networks of GB. The analysis has identified the specific networks that are responsible for triggering investment and quantified their contribution to the overall network investment requirements. Table 2 details the network specific investment levels as a percentage of the overall gross TOTEX for the ten most popular distribution network types in GB.

Table 2: Distribution network specific driven investment

Network type listed by volume	Number of networks	Network investment (% of 2030 TOTEX)	Network investment (% of overall 2015 – 2030 TOTEX)
LV8 Terraced street	336,922	43.2%	19.5%
LV7 New build housing estate	149,493	0.0%	0.7%
LV6 Suburban street	122,765	16.9%	9.1%
LV4 Business park	70,119	0.0%	0.0%
LV2 Dense urban	50,099	0.0%	0.0%
LV19 Meshed terraced street	44,482	0.0%	0.0%
LV3 Town centre	32,154	10.6%	7.9%
LV17 Meshed suburban street	26,208	0.0%	0.1%
LV10 Rural village (underground)	24,802	8.9%	9.5%
LV9 Rural village (overhead)	24,122	0.2%	5.3%

Table 2 shows that for the year 2030, distribution network investment occurs in the most prevalent network types of the GB distribution network which in turn significantly increases the magnitude of the overall network investment for the year 2030. Hence, it can be seen in Table 2 that the first and third most popular type of distribution networks in GB, i.e. LV8 and LV6 respectively, contribute together to 60% of the overall network investment for the year 2030. It should also be noted that despite some networks not contributing to network investment in the year 2030, they may contribute in some other years during the period 2015 – 2030. For instance, distribution networks LV7 and LV17 do undergo investment over the period of analysis.

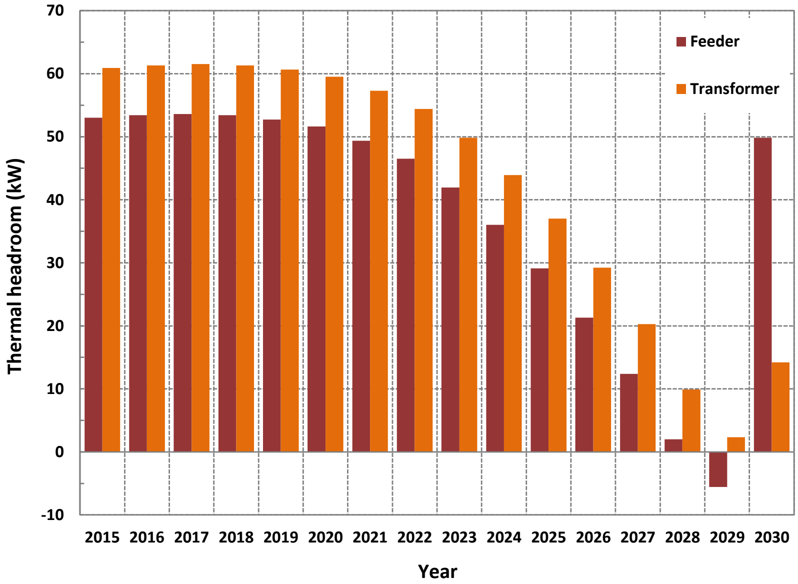


Figure 9: Thermal headroom for one cluster group of the "LV8 terraced street" distribution network

It can be observed in Figure 9, that the thermal headroom of feeders and transformers for the LV8 networks decreases until 2029 as the utilisation of the network assets increases as a consequence of load and LCTs growth. In the year 2030, the network is not capable of accommodating more load and LCTs without intervention. In this respect, reinforcing the network, through the deployment of a mixture of conventional and smart solutions, increases the network thermal headroom as demonstrated in Figure 9.

In other words, the fact that the networks that drive investment requirements in the year 2030 coincide with those that are more prevalent, cause the network expenditure to spike in 2030.

To quantify the level of investment required in distribution networks, the Transform Model must evaluate the impacts caused by the integration of LCTs in the distribution network. To ensure these impacts are captured in a consistent manner, the Transform Model uses the concept of "headroom". Headroom refers to the difference between the load experienced on a network or asset, and the rating of that network or asset. If the rating exceeds the load, then there is a positive amount of headroom and investment is not required. However, once load exceeds rating then the headroom figure is negative and investment to release additional headroom must be undertaken. The advantage to using headroom in this way is that it allows numerous parameters to be discussed on a common base. The Transform Model currently evaluates headroom for three different parameters: thermal, voltage and fault level. Based on the concept of headroom, the effect of the LCTs on these parameters can be captured simultaneously; i.e. if a particular LCT contributes to a reduction in both thermal and voltage headroom, this can be easily identified[13].

4.2 Distribution network investment drivers

The analysis has identified the key drivers for network investment and measured their impact as the magnitude of expenditure per driver has been quantified. Figure 10 shows the drivers for triggering network investment disaggregated by load related investment (i.e. driven by changes in the uptake levels of EVs, HPs, etc.) and distributed generation related investment (i.e. driven by changes in the uptake levels of PV, Wind, etc.). Load related investments are further disaggregated into overloaded feeders,

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[13] EA Technology et al., Aug 2012. "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks". DECC and Ofgem Smart Grid Forum.

transformers and voltage legroom[14] problems whilst distributed generation related investments are linked to voltage headroom problems.

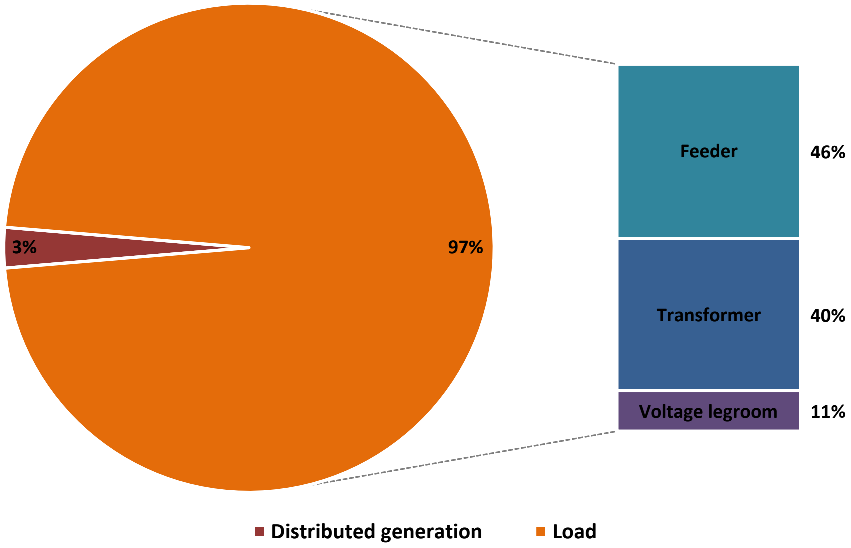

Figure 10: Distribution network investment drivers for "High" trajectory

It can be observed in Figure 10 that changes in load (i.e. HPs and EVs), over the period of analysis, are responsible for driving 97% of the overall expenditure for network investment. Network assets are deployed to resolve mainly thermal problems related to overloaded feeders and transformers. Network expenditure driven by changes in distributed generation (i.e. PV and Wind) account for only 3% of the overall expenditure related to LCTs during the period 2015 – 2030.

4.3 Contribution of LCTs to distribution network investment

The identified drivers for distribution network investment can be further disaggregated into each of the LCTs considered to quantify their individual contribution to network expenditure. Figure 11 depicts the contribution of each LCT to network expenditure for the "High" trajectories over the period 2015 – 2030.

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[14] Voltage headroom refers to the margin between the observed voltage and the upper voltage limit and legroom refers to the margin between the observed voltage and the lower voltage limit. At low voltage these limits are set at +10%/-6% of nominal voltage.

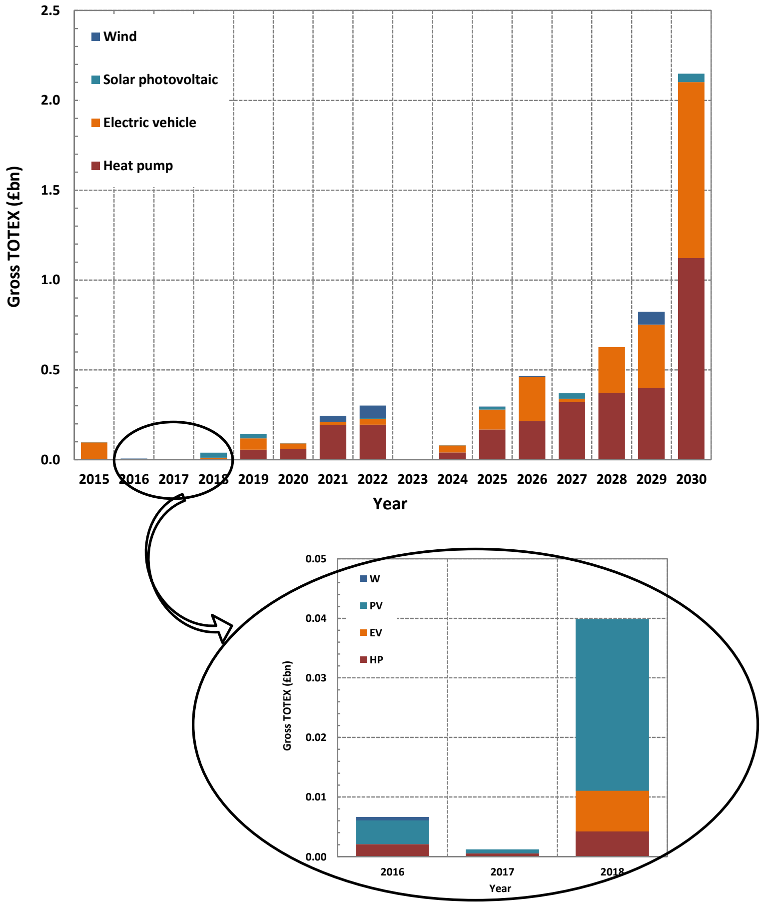

Figure 11: Distribution network investment driven by LCTs for “High” trajectory

Figure 11 shows that investment in distribution network assets is triggered by different LCTs over time. It can be seen that early in the period (i.e. inset of Figure 11), distribution network investment is driven by distributed solar photovoltaic as the presence of heat pumps and electric vehicles in the network are relatively low. Beyond 2020, the network investment triggered by heat pumps and electric vehicles overtakes that of distributed solar photovoltaic and wind.

It is noted that the Transform Model considers a variety of representative feeder types composed of Extra High Voltage networks (i.e. supplied from a grid transformer 132/33kV), High Voltage networks (i.e. supplied from a primary transformer 33/11kV) and Low Voltage networks (e.g. “urban”, “suburban”, “rural”, etc.)[15]. Thus, distributed network related expenditure driven by distributed solar photovoltaic and wind in networks that operate at a voltage level of 132kV or above are excluded from this work.

It should also be noted that the Transform Model adopts a “bottom-up” approach as it has been conceived to be more representative of investment levels on the LV and HV networks (i.e. those below 33kV). Clearly, a significant number of large distributed generation connections occur at these higher voltages and the Transform Model does not make any attempt to model in detail the costs associated with the connection of these distributed generators to the grid. The reason for this consideration is that such connections are often clustered around certain geographic areas, making additional connections very expensive. This will manifest itself in “real” generation connections, but because the costs are calculated on a completely bespoke basis dependent on the peculiarities of the network location; and also as such costs would not generally be socialised through a DUoS charging mechanism (they would be borne by the generation developers), the Transform Model does not seek to evaluate them.

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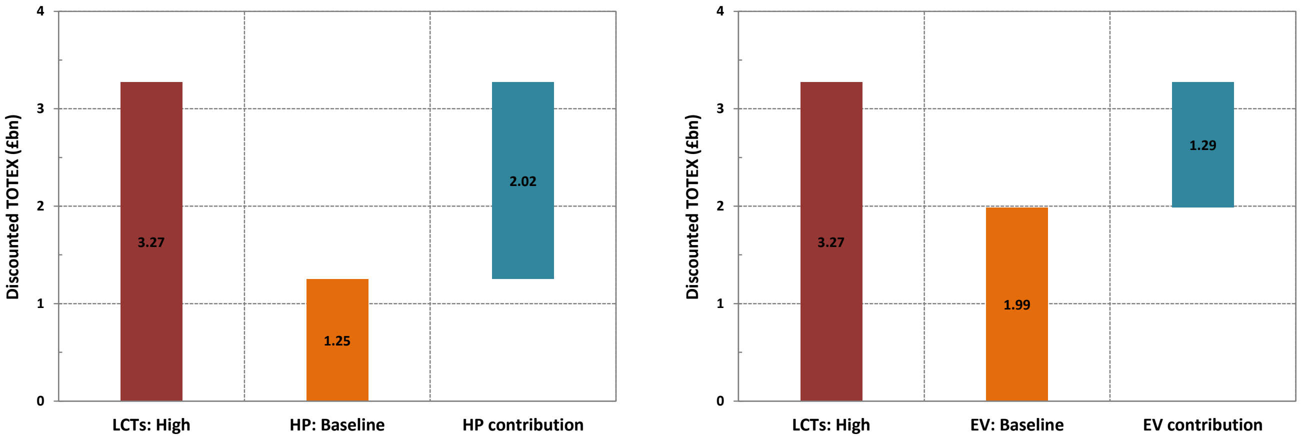
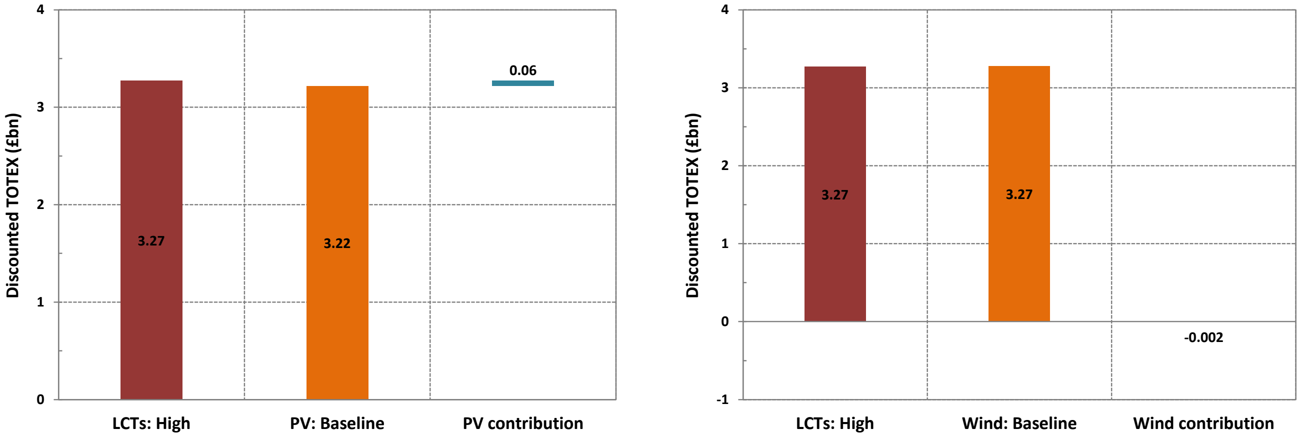
[15] ENA, 2014. “The Distribution Code and the Guide to the Distribution Code of Licensed Distribution Network Operators of Great Britain”. Energy Networks Association, Issue 2, Feb 2014. http://www.dcode.org.uk/assets/files/dcode-pdfs/Distribution%20Code%20v%2022.pdf

It is also worth noting that the connection of distributed generation at the low voltage level (e.g. domestic PV) is carried out based on an assumption that connections are equally likely at all points along the LV feeder. This is important as it means that connections are evenly distributed along these circuits, resulting in a fairly low probability of the need for reinforcement due to voltage headroom breaches arising. If all the connections on a particular feeder are, in practice, at the substation end of the circuit, then it is possible that a headroom breach will be observed whereas it would not manifest itself if the connections were spread or clustered at some point further along the circuit. Therefore, there will be some real-world cases where investment is required (because of this clustering at the feeding end of the circuit) which the Transform Model would not foresee. It should also be noted that the same rationale applies to other technologies (e.g. heat pumps and electric vehicles) and the Transform Model assumes an even distribution of these along a feeder. Again, if these were clustered at the remote end (rather than the feeding end) then this could cause voltage legroom breaches. It is possible to alter the Transform Model to bias it towards examining these cases, but when considering a GB-wide approach, it is considered to be more statistically representative for the connections of LCTs to have equal likelihood of connecting at the feeding end, part way along, or at the remote end of the circuit.

Figure 12 details the magnitude of the overall expenditure for network investment attributed to each LCT for the "High" trajectory over the period 2015 – 2030.



(a) Heat pump **(b) Electric vehicle**



(c) Solar photovoltaic **(d) Wind**

Figure 12: Overall distribution network investment driven by individual LCTs for "High" policy trajectory

From the interpretation of Figure 12a, it can be observed that the presence of LCTs in the "High" trajectory (i.e. "LCTs: High") are estimated to drive an overall network expenditure of £3.27bn. Subsequently, considering heat pumps in the "Baseline" trajectory whilst all other LCTs remain in the

"High" trajectory (i.e. "HP: Baseline"), the overall network expenditure is estimated to be £1.25bn. The difference between the distribution network expenditure in both cases (i.e. "LCTs: High" and "HP: Baseline") represents the level of network investment driven by heat pumps. Hence, heat pumps are estimated to drive £2.2bn (i.e. "HP contribution") out of the overall £3.27bn of the expenditure required for network development.

It is seen in Figure 12 that the overall (i.e. 2015 – 2030) network expenditure driven by the electrification of heating sector is nearly two times higher than that of the transport sector. The overall network expenditure driven by the solar photovoltaic and wind is practically negligible. A slight negative contribution from wind generation indicates that this technology supports the network by releasing headroom. It should be emphasised that year on year, network investment is triggered by different LCTs as aforementioned. Nonetheless, in overall terms for the period 2015 – 2030, as the uptake levels of heat pumps and electric vehicles largely dominates over those of solar photovoltaic and wind, the expenditure requirements for network development are mostly driven by the electrification of heating and transport sectors.

In order to devise a single factor to represent the contribution of individual LCTs to LCT related distribution network investment, various simulation runs were performed in the Transform Model for different combinations of trajectories (i.e. "High", "Central" and "Low") and the range of the contribution of LCTs to network investment was measured. It has been observed that under DECC's trajectories and for each LCT, the contribution range was fairly narrow and therefore a single contribution factor for each LCT can be derived with reasonable certainty. Figure 13 presents the observed contribution factors of each individual LCT to distribution network investment over the period 2015 – 2030.

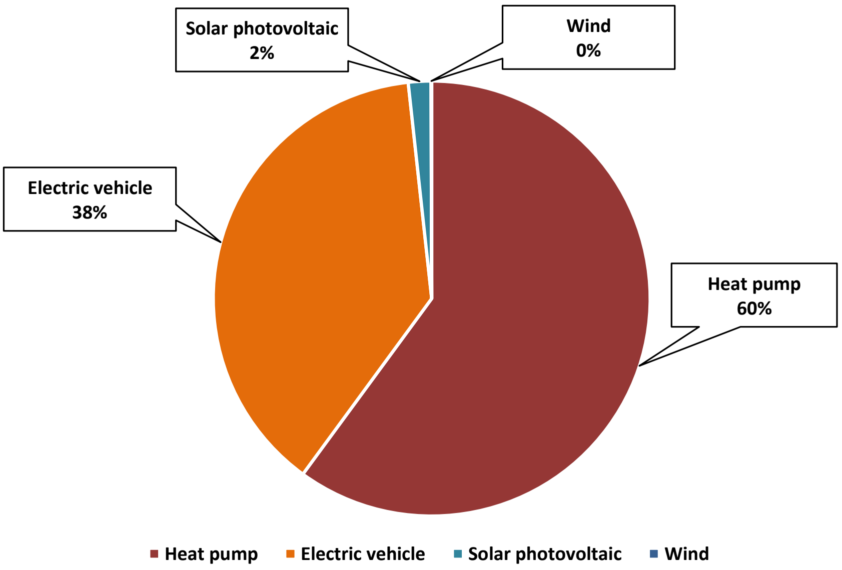


Figure 13: Contribution of LCTs to LCT related distribution network investment, 2015-2030

Figure 13 shows for load technologies that heat pumps and electric vehicles considerably drive network investment expenditure as they significantly increase the load in distribution networks and consequently decrease circuit's headroom. For distributed generation technologies, solar photovoltaic and wind have low and no impact respectively, on expenditure for network investment as these technologies generally contribute to offset load growth imposed by the electrification of heating and transport sectors.

The range of contribution of each LCT to the overall expenditure for distribution network investment has been measured by performing various simulations runs in the Transform Model for different combinations of LCTs' trajectories (i.e. "High", "Central" and "Low"). The observed ranges are provided in the following subsections for each LCT. The contribution range for each LCT is expressed through the lower and upper bounds of the network expenditure driven by specific LCT trajectory considering different combination of trajectories for all other LCTs.

4.3.1 Heat pumps

Table 3 presents the range of the contribution of heat pumps to expenditure requirements for distribution network investment for each trajectory over the period 2015 – 2030.

Table 3: Range of contribution of heat pumps to distribution network investment

Heat pumps' trajectory	Discounted TOTEX (£bn)	
	Lower bound	Upper bound
Low	0.62	0.79
Central	0.99	1.54
High	1.22	2.02

It can be seen in Table 3 that for the uptake levels of heat pumps specified by the "High" trajectory, the contribution of this LCT to distribution network investment requirements ranges from £1.22bn to £2.02bn. The lower and upper bounds of the range correspond respectively, to the minimum and maximum contribution that heat pumps can make to distribution network investment in the "High" trajectory considering all possible combination of trajectories for all other LCTs. It can be also seen in Table 3 that the range broadens from 27% in the "Low" trajectory to 61% in the "High" trajectory.

4.3.2 Electric vehicles

Table 4 details the range of the contribution of electric vehicles to expenditure requirements for distribution network investment for each trajectory over the period 2015 – 2030.

Table 4: Range of contribution of electric vehicles to distribution network investment

Electric vehicles' trajectory	Discounted TOTEX (£bn)	
	Lower bound	Upper bound
Low	0.40	0.78
Central	0.44	0.94
High	0.50	1.29

It can be observed in Table 4 that the contribution of electric vehicles to distribution network investment requirements ranges from a minimum of £0.40bn in the "Low" trajectory to a maximum of £1.29bn in the "High" trajectory.

4.3.3 Solar photovoltaic

Table 5 provides the range of the contribution of solar photovoltaic to expenditure requirements for distribution network investment for each trajectory over the period 2015 – 2030.

Table 5: Range of contribution of solar photovoltaic to distribution network investment

Solar photovoltaic's trajectory	Discounted TOTEX (£bn)	
	Lower bound	Upper bound
Low	0.017	0.054
Central	0.018	0.054
High	0.018	0.055

Table 5 shows that the contribution of solar photovoltaic to distribution network investment requirements ranges approximately from £0.018bn in any of the trajectories to £0.055bn.

4.3.4 Wind

Table 6 explores the range of contribution of wind to expenditure requirements for distribution network investment for each trajectory over the period 2015 – 2030.

Table 6: Range of contribution of wind to distribution network investment

Wind's trajectory	Discounted TOTEX (£bn)	
	Lower bound	Upper bound
Low	-0.002	-0.001
Central	-0.002	-0.001
High	-0.002	-0.001

It is observed in Table 6 that the contribution of wind to the overall expenditure requirements for the development of distribution networks, over the period 2015 – 2030, is practically negligible.

4.4 Conclusions

The analyses performed by EA Technology based on the uptake trajectories provided by DECC quantified and assessed the impact of LCTs on distribution network investment, identified its drivers and measured their respective impact. The key findings of the analyses can be summarised as follows:

- Investment in distribution network assets is triggered by different LCTs over time. In the short term, LCT related distribution network investment is observed to be driven by distributed solar photovoltaic and distributed wind as the presence of heat pumps and electric vehicles in the network are relatively low. In the long term, the electrification of the heating and transport sectors are estimated to trigger most of the LCT related investment requirements for distribution network development.
- Generation technologies such as distributed solar photovoltaic and wind have low or no impact respectively, on the overall expenditure requirements for distribution network investment (i.e. total network expenditure for the period 2015 – 2030) when modelled as having equal probability of connecting at various points along a circuit. These LCTs are observed to contribute to offset load growth imposed by the electrification of heating and transport sectors. Distributed solar photovoltaic are estimated to drive 2% of the overall LCT related distribution network expenditure. It should be noted that this refers only to generation connected at 33kV and below and only costs that are socialised through DUoS (i.e. not costs associated with large generators that are borne by developers).
- Load technologies such as heat pumps and electric vehicles significantly increase the load on distribution networks driving the overall expenditure requirements for distribution network investment linked to LCT uptake (i.e. total network expenditure for the period 2015 – 2030) considerably. Heat pumps are estimated to drive 60% of the overall LCT related distribution network expenditure whilst electric vehicles drive 38%, assuming that each of these LCTs shares the same trajectory; in other words they are both on the 'high' trajectory or they are both on the 'low' trajectory. Clearly if one is on a different uptake trajectory to the other, the percentages will change.
- The overall LCT related expenditure requirements for distribution network investment in the period 2015 – 2030 are mainly driven by the electrification of heating and transport sectors (i.e. deployment of heat pumps and electric vehicles).

5 Policy driven distribution network investment

This section investigates the impact of policies with the integration of LCTs in the GB distribution networks. DECC's policies under investigation are applied into the Transform Model to quantify and assess their impact on expenditure requirements for distribution network investment and to inform the development of Government policies. For instance, the expected electrification of heating and transport sectors (e.g. HPs, EVs), the increasing presence of distributed generation technologies (e.g. PV, Wind, etc.) and the increasingly stringent regulations on the energy performance of buildings are of particular interest as their integration imposes significant challenges to the technical and cost efficient development and operation of electricity distribution networks. Therefore, DECC proposed to examine the impact that energy policies "already in place or planned to a sufficient degree of detail" and the combined impact of Electricity Market Reform and Feed-in Tariffs may cause on electricity distribution network investment.

The trajectories (i.e. "Low", "Central" and "High") characterising the uptake levels of each LCT, (i.e. HP, EV, PV and Wind) have been combined in a specific manner to perform the analyses presented in section 5. Table 7 presents an overview of the main trajectory combinations considered in this section. It is noted that other combinations were considered where appropriate to quality assure some of the analyses undertaken in the report.

Table 7: Main combinations of LCT trajectories for the analyses performed in section 5

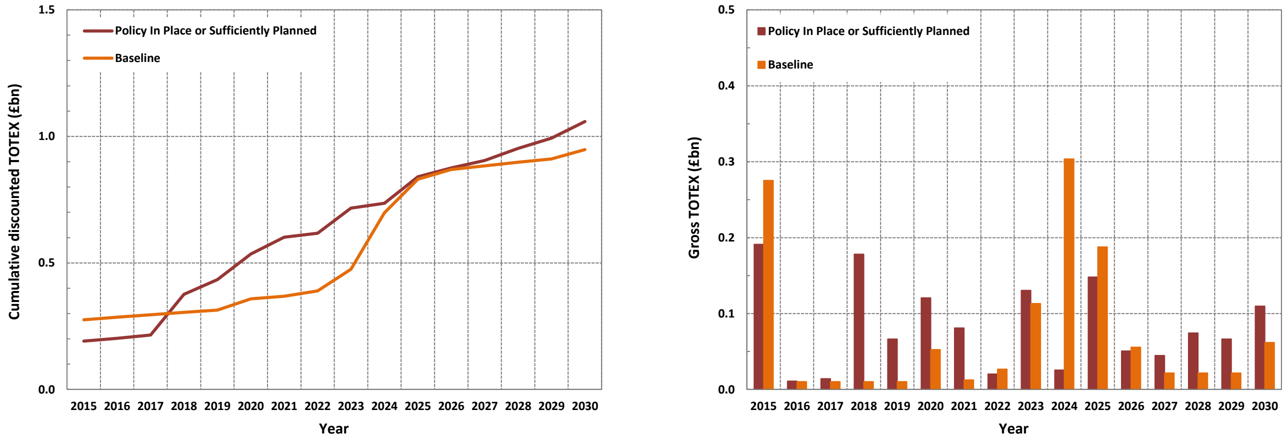
Report section	Analysis	Heat pumps	Electric vehicles	Solar photovoltaic	Wind
5 Policy driven distribution network investment	5.1 Policy "in place or sufficiently planned"	Low	Low	Central	Central
		Baseline	Baseline	Baseline	Baseline
	5.1.2 DECC's Energy and Emissions Projections	Reference Scenario	Reference Scenario	Reference Scenario	Reference Scenario
		Baseline Scenario	Baseline Scenario	Baseline Scenario	Baseline Scenario
	5.2 Electricity Market Reform	Baseline	Baseline	High	High
		Baseline	Baseline	Central	Central
		Baseline	Baseline	Low	Low
		Baseline	Baseline	Baseline	Baseline

5.1 Policy "in place or sufficiently planned"

This analysis explores the impact of policies that are "already in place or planned to a sufficient degree of detail" on expenditure requirements for distribution network investment. This scenario, termed as policy "in place or sufficiently planned", includes policies that have a direct impact on the uptake of LCTs only. However, it is important to note that it has not been possible to accurately account for some wider Government policies in this scenario, such as policies related to energy efficiency, i.e. supplier obligations, building regulations and Energy-Using products policy and therefore these have not been included. Section 5.1.2 provides an indication of the impact of policies that include energy efficiency measures.

In the analysis, policy "in place or sufficiently planned" is represented through the combination of "Low" trajectory for heat pumps and electric vehicles and "Central" trajectory for solar photovoltaic and wind. Section 3, Figure 4 to Figure 7 shows the uptake trajectories for the LCTs. This policy is then compared with the "Baseline" trajectory for the uptake levels of all LCTs to evaluate its impact. It is stressed that this analysis assumes that the heat pumps deployed under policy "in place or sufficiently planned" are of hybrid type which may not necessarily reflect current policy, such as the Renewable Heat Incentive (RHI) which incentivises the deployment of non-hybrid heat pumps. Section 6.2 illustrates that the deployment of non-hybrid heat pumps is likely to increase the network investment requirements relative to hybrid heat pumps. Nevertheless, the impact caused is likely to be relatively small under policy "in place or sufficiently planned" as it assumes "Low" trajectory for the heat pump deployment over the period to 2030.

Figure 14 provides the range of distribution network expenditure driven by policy "in place or sufficiently planned" over the period 2015 – 2030.



(a) Cumulative discounted TOTEX **(b) Gross TOTEX**

Figure 14: Distribution network investment under policy "in place or sufficiently planned"

Figure 14a shows that the overall network expenditure to 2030 under policy "in place or sufficiently planned" is fairly close to that of the "Baseline" (i.e. £1.1bn against £0.9bn respectively). The policy "in place or sufficiently planned" initiates the transition process to a low carbon economy of the future, incentivising the deployment of LCTs amongst other measures, without increasing significantly the expenditure requirements for distribution networks. It can also be seen that policy "in place or sufficiently planned" achieves a more gradual growth in network expenditure over the period to 2030 instead of delivering the bulk of network expenditure concentrated in a relatively short period of time as observed in the "Baseline" trajectory from 2023 to 2026.

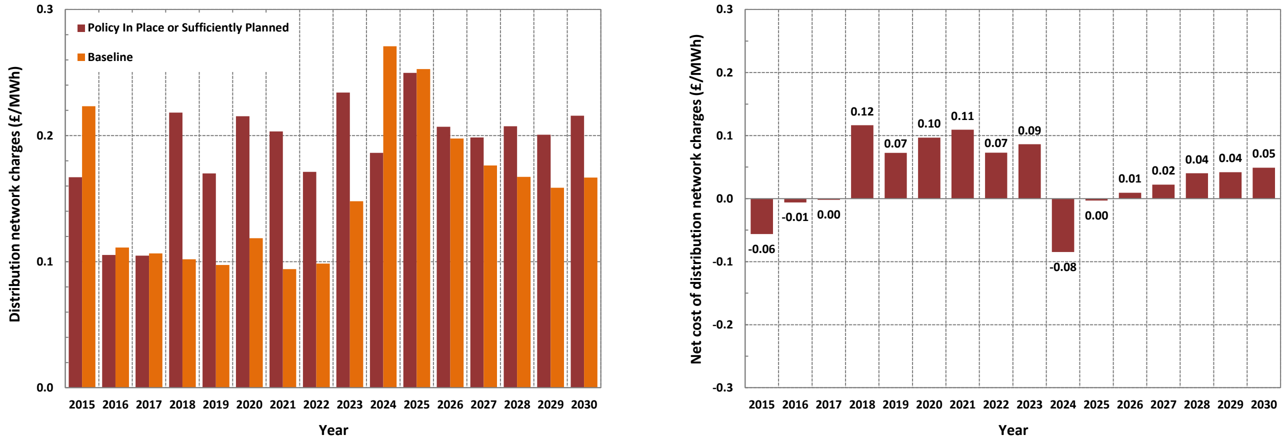
In contrast, the "Baseline" trajectory presents a slow growth in network expenditure to 2023 as the network is able to accommodate the "Baseline" uptake levels of LCTs on a slow incremental basis adopting lower cost solutions that deliver lower headroom gains. Nevertheless, beyond 2023, the uptake levels of LCTs become significant enough such that attempting to adopt this incremental approach is not technically and economically efficient and therefore substantially higher network investments are required.

Figure 14a also shows that for the period 2015 – 2017, the overall expenditure required for network development is higher in the "Baseline" trajectory than in the policy "in place or sufficiently planned". It has been observed (i.e. Section 3) that both trajectories have very similar uptake levels of heat pumps and electric vehicles during the period, however, policy "in place or sufficiently planned" registers higher uptake levels of solar photovoltaic and wind. It was previously stated that if solar PV was in the "High" uptake trajectory, it could trigger some network investment requirements. Here, with the "Central" trajectory, it is shown to be at a more "optimal" level, whereby the uptake level is not high enough to drive network investment, but is of sufficient magnitude to "net-off" some demand. Therefore, it provides a small overall saving as against the "Baseline" trajectory where such netting off does not occur. Beyond 2017 the uptake levels of LCTs are more noticeable in policy "in place or sufficiently planned" than in the "Baseline" trajectory resulting in higher levels of network investment under policy "in place or sufficiently planned".

5.1.1 Distribution network charges

The analysis investigates the impacts of policies “in place or sufficiently planned” on GB distribution network charges. The Transform Model quantifies distribution network charges based on a similar mechanism to that set by Ofgem for the Distribution network Use of System charges (DUoS charges). Broadly, Ofgem’s price control sets the amount of money (i.e. allowed revenue) that can be earned by DNOs over the length of the price control period[16]. DNOs recover their allowed revenues from their charges to suppliers who in turn pass these costs through to customers. The revenues have to be set at a level which covers the DNOs’ costs and allows them to earn a reasonable return subject to them delivering value for consumers. The return related to network investment and operating cost has been set based on the Regulated Asset Value (RAV) calculation[17].

Figure 15 provides an estimation of the distribution network charges and associated net costs driven by the policy “in place or sufficiently planned” over the period 2015 – 2030. These distribution network charges are compared against those attained from the “Baseline” trajectory to evaluate its impact.



(a) Distribution network charges **(b) Net cost of distribution network charges**

Figure 15: Distribution network charges and net costs

Figure 15a shows that on average over the period 2015 – 2030, policy “in place or sufficiently planned” is estimated to modestly increase the distribution network charges by 3 pence compared to the “Baseline” trajectory. Specifically, the distribution network charges increase from £0.16/MWh in the “Baseline” trajectory to £0.19/MWh in the policy “in place or sufficiently planned” when considered in gross terms.

The current costs per MWh that are paid by domestic customers are of the order of magnitude of £24 – £35[18] implying that the level of change described in Figure 15a (i.e. 3p/MWh) represents approximately 0.1% increase to an electricity domestic customer on the portion of their bill payable to the DNO.

It can be seen in Figure 15a that this average increase over the period is constituted of dissimilar network charge impacts year-on-year. For instance, for the year 2018, the network charges increase from £0.10/MWh in the “Baseline” trajectory to £0.22/MWh in the policy “in place or sufficiently planned” whilst for the year 2024, the network charges decrease from £0.27/MWh in the “Baseline” trajectory to £0.19/MWh in the policy “in place or sufficiently planned”.

Figure 15b compares the distribution network charges driven by policy “in place or sufficiently planned” against the “Baseline” trajectory. Positive numbers indicate that policy “in place or sufficiently planned” drives higher network charges than the “Baseline” trajectory. It can be seen in Figure 15b that for most of

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[16] Ofgem, 2013. “Factsheet 117 – Price Controls Explained”. Office of Gas and Electricity Markets, Mar 2013.

[17] Ofgem 2009. “Financial Model Manual – Distribution Price Control Review 5 (DPCR5)”. Office of Gas and Electricity Markets, 10 Dec 2009.

[18] ENA, 2014. “Distribution Use of System Charges”, Energy Networks Association, Archives, 2014. http://www.energynetworks.org/electricity/regulation/duos-charges/distribution-use-of-system-charges/

the years throughout the period 2015 – 2030, policy “in place or sufficiently planned” results in costs (i.e. positive number) relative to the “Baseline” trajectory as it drives higher network charges.

5.1.2 DECC’s Energy and Emissions Projections

Projections of the United Kingdom (UK) energy demand, supply and greenhouse gas (GHG) emissions have been published by DECC on a regular basis, to inform Government energy and environmental analysis, since 2000[19]. This analysis uses the 2013 updated energy and emission projections (UEP) provided by DECC for this project, to investigate their impact on the distribution network investment and policy development. Note that the 2014 UEP estimates, which have since been published, were not yet available when this project was undertaken.

The energy projections include the majority of policies that impact directly on energy demand, supply and greenhouse gas emissions. The majority of policies that impact directly on energy demand are modelled as reductions or increases in demand for different types of energy (gas, electricity, renewables, etc.). The demand equations in the DECC Energy and Emissions Model projects what demand would be in the absence of these policy impacts. The projected impacts are then subtracted or added to demand as appropriate. The emissions projections include all policies which directly affect GHG emissions and to which the Government is committed. Other policies are incorporated into the modelling directly e.g. through price impacts. Policies are included where funding has been agreed and where decisions on policy design are sufficiently advanced to allow robust estimates of policy impacts to be made. The energy projections are termed in this analysis as “UEP Reference Scenario”.

Specifically, the analysis highlights the impact of policies that relate directly to energy demand. In this sense, an emphasis is given to policies related to energy efficiency, e.g. supplier obligations, building regulations and Energy-Using products policy. However, it should be stressed that the impacts from the energy projections scenario (i.e. includes energy efficiency policy) and the policy “in place or sufficiently planned” scenario (i.e. does not include energy efficiency policy) are not strictly additive as there are other policy measures that overlap in both scenarios. Hence, the UEP is used as a proxy to represent the impacts associated with energy efficiency policy.

The impact of the “UEP Reference Scenario” is assessed against a baseline projection termed as “UEP Baseline Scenario” that only contains policies that existed before the UK Low Carbon Transition Plan[20]. In essence, it represents a “business as usual” projection, i.e. a projection of what one would expect to happen in the absence of the policy that has been implemented, or is at a “sufficiently advanced” stage, since July 2009. Concerning the uptake levels of LCTs, it is acknowledged that there is a slight difference between the “UEP Reference Scenario” and the “UEP Baseline Scenario”, however, since the difference is minimal, its material impact on network investment requirements is negligible.

Figure 16 displays the annual evolution of the winter peak demand for the “UEP Reference Scenario” and “UEP Baseline Scenario” over the period of 2015 – 2030.

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[19] DECC, “Energy and Emissions Projections”. In the National Archive. http://webarchive.nationalarchives.gov.uk/20130106105028/http:/www.decc.gov.uk/en/content/cms/about/ec_social_res/analytic_projs/en_emis_projs/en_emis_projs.aspx#previous-projections

[20] HM Government, 2009. “The UK Low Carbon Transition Plan”. HM Government, 15 Jul 2009.

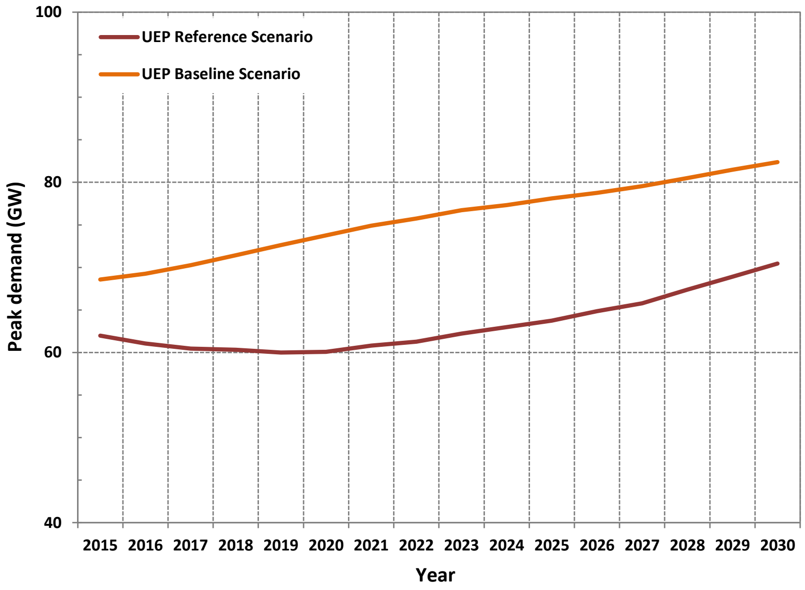

Figure 16: Winter peak demand for the UEP scenarios

Figure 16 shows for the “UEP Reference Scenario” that peak demand is projected to fall until 2020 due to the introduction of energy efficiency policies. Peak demand projections then increase over the period 2020 – 2030. The “UEP Baseline Scenario” presents a linear increase throughout the period, such that the absence of policies that came into force post 2009 result on average, in a 12GW higher peak demand over the period.

It is noted that the load curves representative of the “UEP Reference Scenario” and the “UEP Baseline Scenario” were provided by DECC to EA Technology. The load curves were constructed assuming the annual energy demand figures from Annex C of the “Updated Energy and Emissions Projections 2013”[21] report. These annual energy demand figures were then converted into hourly load curves using National Grid’s load curve assumptions to produce the final load curves for this analysis.

The analysis has explored the impact that DECC’s energy projections cause on expenditure requirements for the development of distribution networks. Figure 17 details the overall network expenditure for investment in network assets for the “UEP Reference Scenario” and “UEP Baseline Scenario” over the period 2015 – 2030.

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[21] DECC, 2013. “Updated Energy and Emissions Projections 2013”. Department of Energy & Climate Change, Sep 2013. https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2013

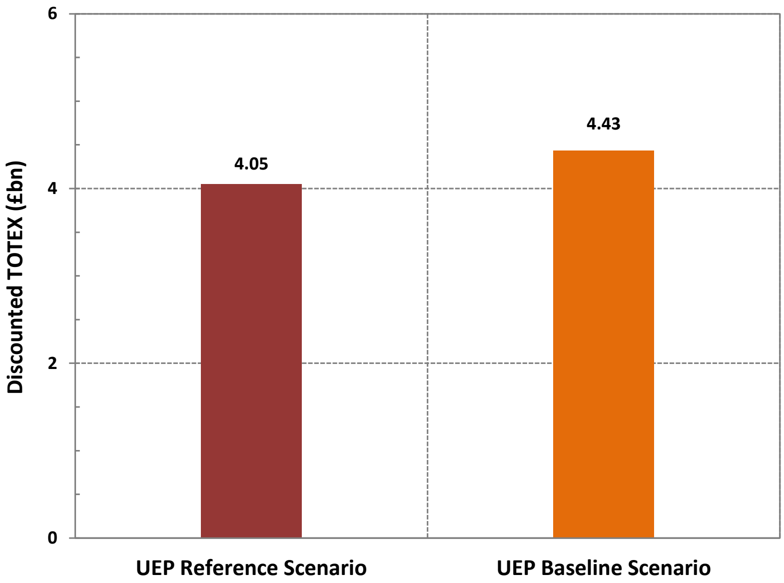


Figure 17: Distribution network investment expenditure for the UEP scenarios

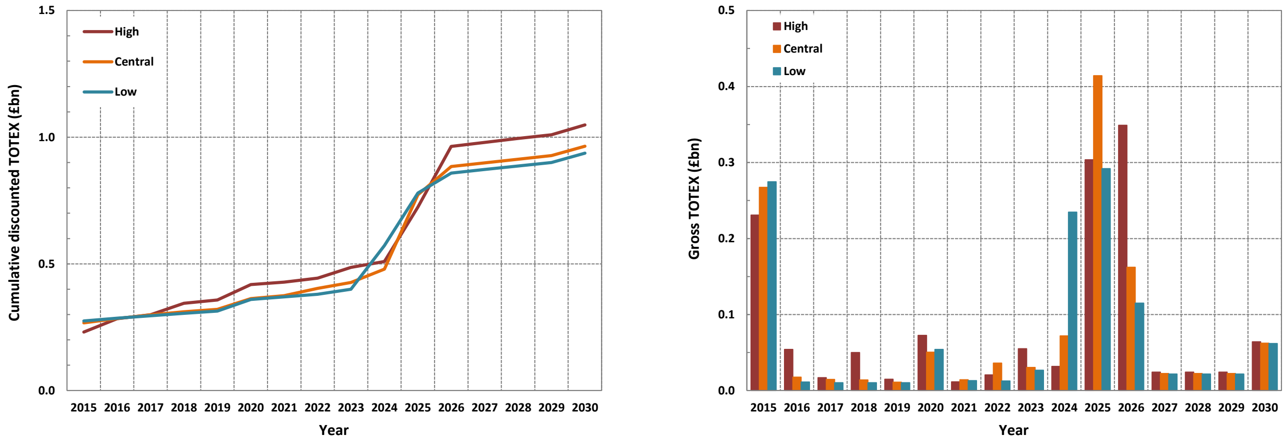
It can be seen in Figure 17 that the energy efficiency policies that underpin the energy projections drive less network expenditure compared to the projections characterised by the absence of policies. In this sense, the overall network expenditure decreases from £4.4bn in "UEP Baseline Scenario" to £4bn in "UEP Reference Scenario".

It should be noted that while Figure 17 demonstrates investment requirements, it should not be correlated with a direct increase in individual consumer bills. This is because, such a correlation would not account for the fact that individual households are consuming less electricity owing to improved energy efficiency.

5.2 Electricity Market Reform (EMR) and Feed-in Tariffs (FiTs)

EMR introduces a series of decarbonisation measures that aim at attracting investment in low-carbon generation, delivering security of supply through a diverse portfolio of electricity sources and ensuring affordable bills to consumers. The small-scale FiTs pays energy users who invest in small-scale (i.e. 5MW or less), low-carbon electricity generation systems for the electricity they generate and use, and for unused electricity they export back to the grid.

From the point of view of this work, EMR and FiTs policy measures have a direct impact in the uptake levels of specific LCTs such as solar photovoltaic and wind that connect directly to distribution networks. In this respect, the impact of EMR and FiTs on expenditure requirements for distribution network investment are measured assuming the that solar photovoltaic and wind trajectories range from "Low", "Central" and "High" whilst the uptake levels for heat pumps and electric vehicles are maintained at "Baseline" levels. Figure 18 specifies the range of distribution network expenditure driven by the introduction the of EMR and FiTs policy measures over the period 2015 – 2030.



(a) Cumulative discounted TOTEX **(b) Gross TOTEX**

Figure 18: Distribution network investment under EMR policy measures

It can be seen in Figure 18a that the range of impact of EMR and FiTs policy measures on the overall magnitude of expenditure required for investment in distribution network assets is relatively narrow during the period of analysis. For instance, the widest range occurs from 2026 to 2030 between “Low” and “High” trajectories and it is estimated to be £0.1bn. This range figure corresponds to approximately 10% of the overall network expenditure driven by EMR and FiTs measures to 2030.

EMR and FiTs policy measures have a relatively low impact on expenditure for network investment as the contribution of distributed solar photovoltaic and wind power technologies towards supplying peak demand and therefore towards constraining distribution network headroom is limited.

Distribution network planning and design standards consider conditions of peak demand to evaluate the need for headroom in distribution networks rather than energy demand requirements. Hence, the ability of distributed solar photovoltaic and wind generation to secure peak demand is the key to answering the question as to how much distribution network headroom should be available for them (i.e. from a security of supply perspective). The variable and uncertain nature of the power output of these distributed generation resources (PV power output generally higher around midday whilst wind power output is intermittent) implies low likelihood of being consistently available during peak demand conditions. Therefore it may not be efficient to invest in distribution network assets to be able to accommodate simultaneous peak outputs from these generation resources.

5.3 Conclusions

The analyses performed by EA Technology, based on the uptake trajectories provided by DECC, quantified and assessed the impact that energy policies “already in place or planned to a sufficient degree of detail” and the combined impact of EMR and FiTs may cause on expenditure requirements for distribution network development. The key findings of the analyses can be summarised as follows:

- The overall network expenditure driven by LCT policy “in place or sufficiently planned” is relatively close to that of a no-policy case (i.e. “Baseline”). Thus, policy “in place or sufficiently planned” initiates the transition process to a low carbon economy of the future, incentivising the deployment of LCTs amongst other measures, without increasing significantly the overall expenditure requirements for distribution network development over the period 2015 – 2030.
- On average over the period 2015 – 2030, LCT policy “in place or sufficiently planned” is estimated to increase the distribution network charges by 3 pence compared to the “Baseline” trajectory. Specifically, the distribution network charges increase from £0.16/MWh in the “Baseline” trajectory to £0.19/MWh in the policy “in place or sufficiently planned”.

- The wider policies that underpin the energy projections, in particular the energy efficiency policies, drive less network expenditure compared to the projections characterised by the absence of policies due to substantially lower levels of electricity demand. The overall network expenditure decreases from £4.4bn in the “UEP Baseline Scenario” to £4bn in the “UEP Reference Scenario” projections.
- EMR and FiTs policy measures have a relatively low impact on expenditure for network investment as the contribution of distributed solar photovoltaic and wind power technologies often has a positive, rather than a negative, impact on network capacity, meaning that its contribution towards constraining distribution network headroom is limited.
- The range of impact of EMR and FiTs policy measures on the expenditure required for investment in distribution network assets is relatively narrow. The overall distribution network expenditure ranges from £0.9bn in the “Low” trajectory to £1bn in the “High” trajectory over the period 2015 – 2030.

6 Sensitivity and further analyses

This section uses a sensitivity analysis approach to investigate the impact of key factors on distribution network investment and policy development. Each sensitivity assumes a change in one variable at a time, with all other assumptions being held constant in order to capture the impact of each variable in isolation. Sensitivity and further analyses have been undertaken to explore the effect of:

- Network development strategy;
- Technology type of heat pumps;
- Distributed generation;
- Distribution network losses;
- Distribution network charging
- Metrics for distribution network expenditure; and
- DNOs' network expenditure for RIIO-ED1 period.

The trajectories (i.e. "Low", "Central" and "High") characterising the uptake levels of each LCT, (i.e. HP, EV, PV and Wind) have been combined in a specific manner to perform the analyses presented in section 6. Table 8 presents an overview of the main trajectory combinations considered in this section. It is noted that other combinations were considered where appropriate to quality assure some of the analyses undertaken in the report.

Table 8: Main combinations of LCT trajectories for the analyses performed in section 6

Report section	Analysis	Heat pumps	Electric vehicles	Solar photovoltaic	Wind
6 Sensitivity and further analyses	6.1 Network development strategy	High	High	High	High
		High	High	High	High
		High	High	High	High
	6.2 Technology type of heat pumps	High	High	High	High
		High	High	High	High
	6.3 Distributed generation	High	High	High	High
		High	High	Baseline(-flat)	Baseline(-flat)
	6.4 Distribution network losses	High	High	High	High
		Low	Low	Low	Low
	6.5 Distribution network charges	High	High	High	High
		Low	Low	Low	Low
	6.6 Metrics for distribution network expenditure	High	High	High	High
		Low	Low	Low	Low

6.1 Network development strategy

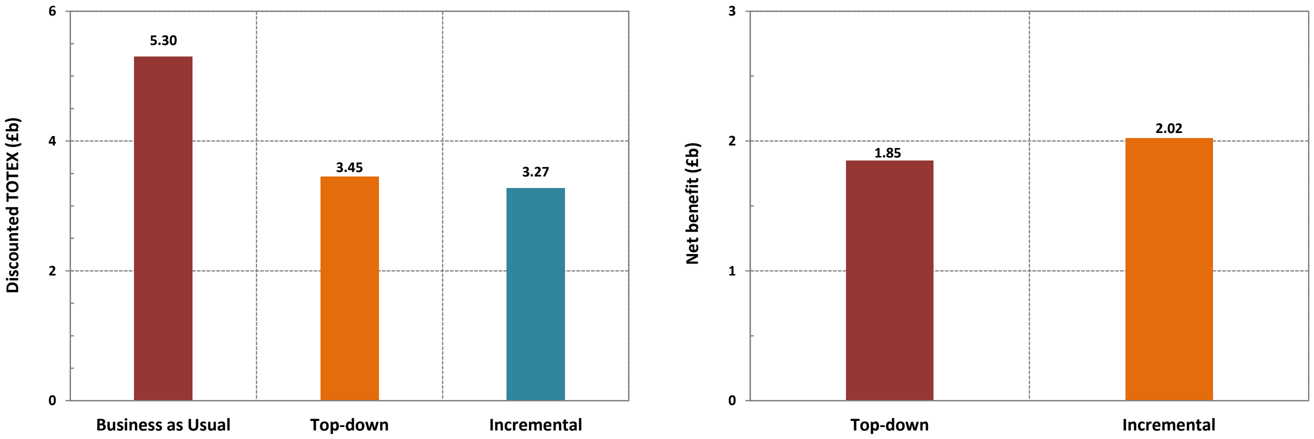
The development of the electricity distribution network infrastructure in the Transform Model is based in one of three distinct strategies as follows:

- Business as Usual (i.e. conventional strategy): deployment of conventional solutions (e.g. new/replacement of feeders and transformers, etc.) only;
- Incremental (i.e. smart strategy): the smart grid case of conventional and smart solutions (e.g. demand side response, electrical energy storage, active network management, etc.), where investment only occurs as and when networks reach their headroom limits. Enablers are deployed alongside the solution variants on an incremental basis.

- Top-down (i.e. smart strategy): the smart grid case of conventional and smart solutions, where an upfront investment of enabler technologies is deployed in advance of need, followed by investment as and when networks reach their headroom limits.

The incremental strategy has been used as the default option in the analyses performed in this work as it aligns with common practice amongst DNOs and it is favoured in most cases (unless LCT uptake rises sharply at a fairly early stage). In the case of this sensitivity analysis the impact of the other network development strategies in the levels of expenditure required to invest and operate network assets is explored.

Figure 19 provides an estimation of the distribution network investment expenditure and net benefits for the different network development strategies. The analysis is based on the "High" policy trajectory for the levels of uptake of LCTs and is carried out for the period of 2015 – 2030.



(a) Investment expenditure **(b) Net benefits**

Figure 19: Distribution network investment expenditure and net benefits

It can be seen in Figure 19a that the use of smart solutions lead to lower network expenditure compared with the use of conventional solutions only. The incremental and top-down strategies represent overall expenditure levels of the order of 60% of the business as usual strategy. Hence, smart network development strategies that use innovative solutions in conjunction with conventional reinforcement options appear to be more cost effective than using solely conventional solutions. The longer the time period considered, the greater the benefit attained via adopting a top-down strategy.

Figure 19b shows the net reduction in the overall network expenditure (i.e. 2015 – 2030) incurred under the two smart network development strategies relative to the conventional strategy. Figure 19b indicates that both smart strategies have a positive net benefit relative to the conventional strategy, as there are more options to choose from when selecting networks solutions within these strategies.

6.2 Technology type of heat pumps

The trajectories used in this project favour the deployment of hybrid heat pumps for domestic consumers. Hence, 90% of the overall domestic heat pump installations are hybrid (i.e. gas and electric) and 10% are non-hybrid (i.e. electric with or without storage capability).

The sensitivity analysis explores the impact of the technology type of heat pumps on distribution network expenditure. Therefore, the analysis considers that the deployment of non-hybrid heat pumps dominates over that of the hybrid technology type. It has been assumed that 90% of the overall domestic heat pump installations are now of non-hybrid type while 10% are of hybrid technology type.

Figure 20 details the range of distribution network expenditure when the presence of a particular type of heat pumps in the network dominates over others. The analysis is based on the “High” policy trajectory for the levels of uptake of LCTs during the period of 2015 – 2030.

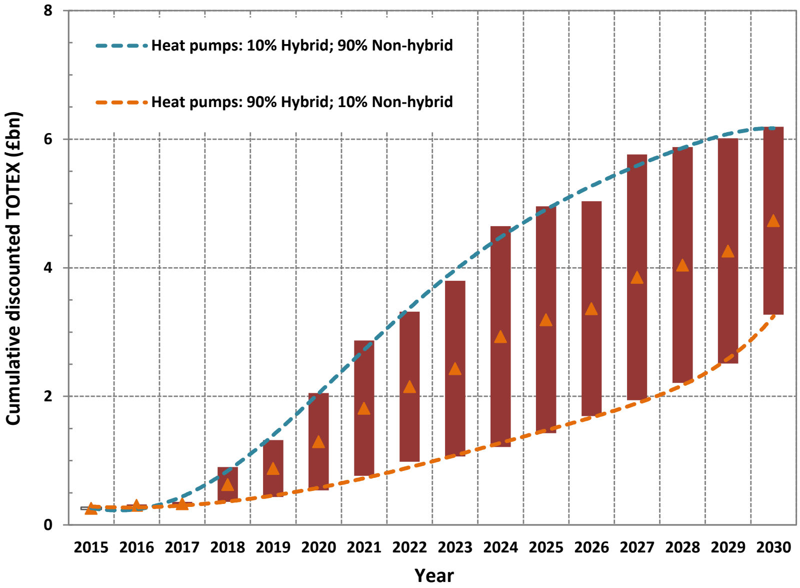
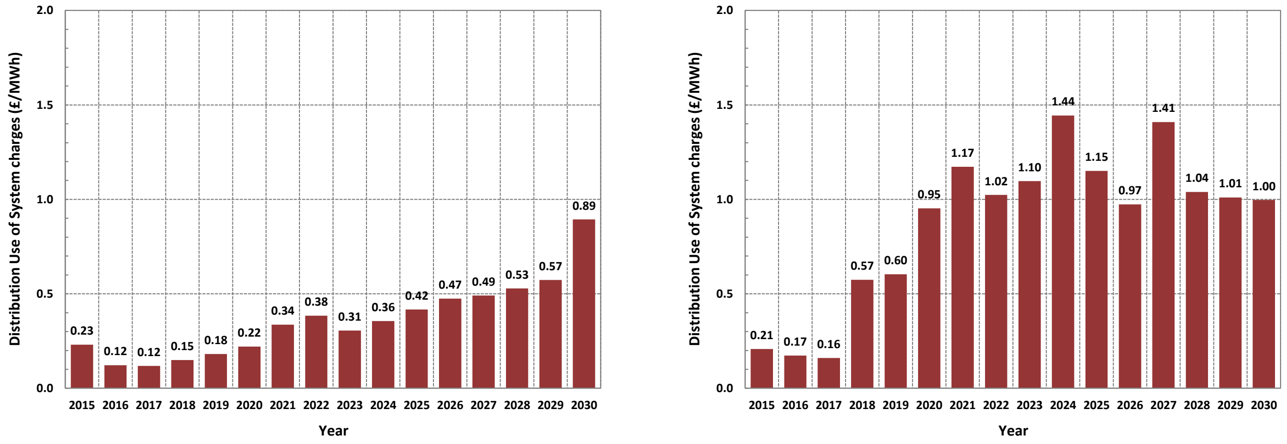


Figure 20: Distribution network investment expenditure under different technology types of heat pumps

It is observed in Figure 20 that the overall distribution network expenditure to 2030 ranges from £3.3bn in 90% hybrid heat pumps to £6.2bn for 10% hybrid heat pumps. Hybrid heat pumps present lower peak demand and energy consumption compared to non-hybrid heat pumps as they burn gas to provide heat during peak demand periods. The impact of this mode of operation results in reduction of the peak and energy load seen by distribution networks.

It can also be seen from Figure 20 that the range of the overall distribution network expenditure to 2018 is relatively narrow as the uptake levels of heat pumps is not large enough to trigger substantial network investment.

The sensitivity analysis explores the range of impacts associated with different technology type of heat pumps on distribution network charges. Figure 21 provides a comparison of the distribution network charges for an overall composition of heat pump installations of 90% Hybrid and 10% Non-hybrid against a composition of 10% Hybrid and 90% Non-hybrid over the period 2015 – 2030.



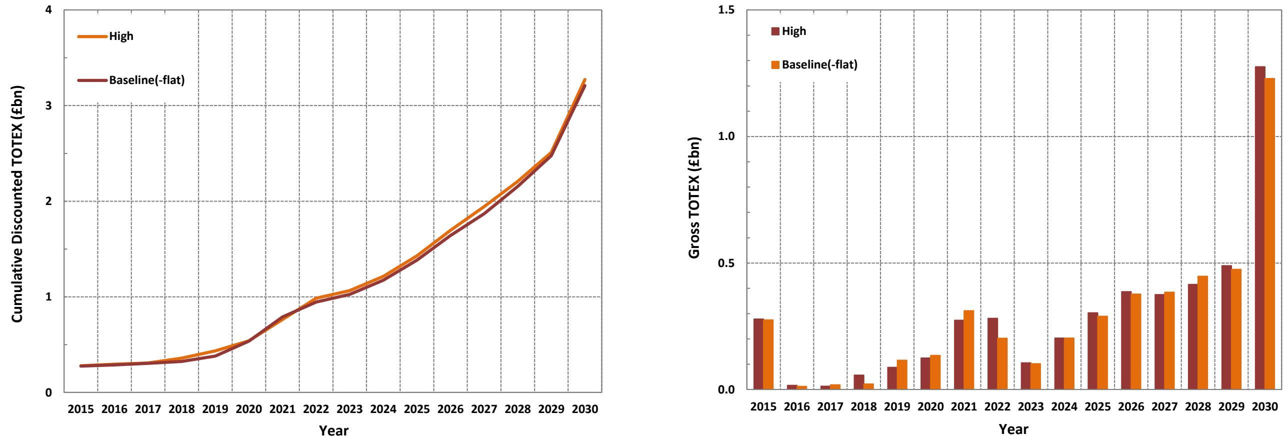
(a) Heat pumps: 90% Hybrid; 10% Non-hybrid **(b) Heat pumps: 10% Hybrid; 90% Non-hybrid**

Figure 21: Distribution network charges

Figure 21 shows that generally, the significant presence of non-hybrid heat pumps in the distribution network in contrast to hybrid, lead to relatively higher network charges. As non-hybrid heat pumps present higher peak demand and energy consumption compared to hybrid heat pumps, the distribution network observes higher requirements for network investment. This behaviour is in turn reflected into higher distribution network charges.

6.3 Distributed generation

The sensitivity analysis explores the impact of distributed generation, i.e. solar photovoltaic and wind, on expenditure requirements for the development of distribution networks. In this respect, the analysis assumes that the deployment of distributed solar photovoltaic and wind generation range from “Baseline(-flat)” to “High” trajectories whilst the uptake levels for heat pumps and electric vehicles are maintained at “High” levels. “Baseline(-flat)” trajectory assumes a constant uptake level throughout the period and equal to that of the year 2015 (i.e. no further DG connections between 2015 and 2030). Figure 22 specifies the range of distribution network expenditure driven by distributed generation over the period 2015 – 2030.



(a) Cumulative discounted TOTEX **(b) Gross TOTEX**

Figure 22: Distribution network investment expenditure driven by distributed generation

It can be seen in Figure 22a that the range of impacts introduced by distributed solar photovoltaic and wind generation on the magnitude of expenditure required for investment in distribution network assets is particularly narrow during the period of analysis. Distributed generation has relatively low impact on expenditure requirements for the development of distribution networks as solar photovoltaic and wind power technologies generally contribute to offset load growth imposed by other LCTs and also because the contribution of these distributed generation resources towards constraining distribution network headroom is limited. However, it should again be noted that this analysis does not include investment requirements on networks with a voltage level above 33kV which are predominately borne directly by developers and may be substantial.

6.4 Distribution network losses

The sensitivity analysis presents the impact that the integration of LCTs in distribution networks may have on network losses. The presence of LCTs in distribution networks tend to increase demand and associated losses as a consequence. This is because variable losses are proportional to the square of the electric current being supplied through the network. Hence, if peak demand increases, the current through the network increases and therefore the losses. Conversely, if demand is reshaped to reduce its peaks (e.g. through demand side response, electrical energy storage, smart charging of EVs, etc.), then the overall losses could be reduced, compared to the original load demand case before reshape.

Figure 23 details the evolution of the distribution network losses observed for the “High”, “Low” and “Baseline” trajectories for the levels of uptake of LCTs and during the period of 2015 – 2030.

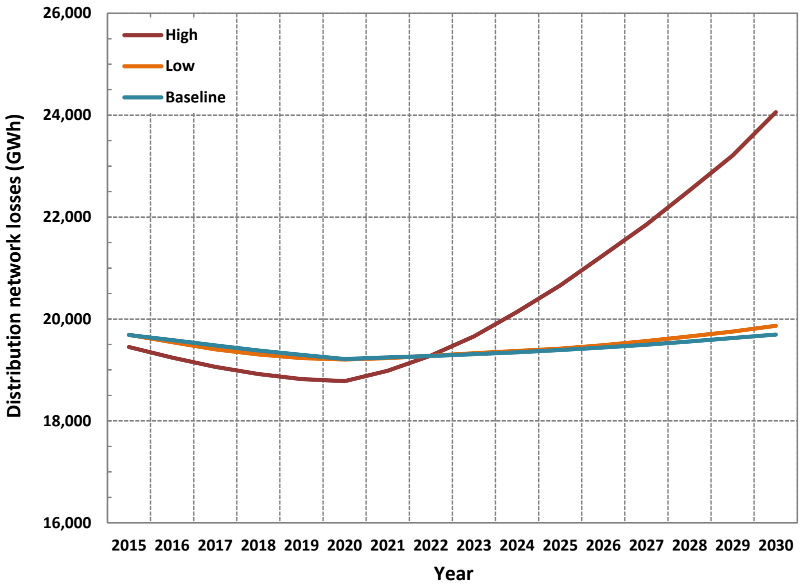


Figure 23: Distribution network losses

Figure 23 shows that for the “High” and “Low” trajectories, there is a noticeable reduction in losses over the period 2015 – 2020 as increased energy efficiency measures and overall network demand reduction outweigh a relatively mild uptake of LCTs. During the period 2020 – 2030, network losses are seen to increase as a result of the projected to growth in load demand, owing to prevailing economic growth and rise in the uptake levels of LCTs. For instance, in the year 2030, distribution network losses increase by 20% from the “Low” to the “High” trajectories. The “Baseline” trajectory shows an almost identical behaviour to the “Low” trajectory.

The observed losses in the distribution network have been converted into a financial figure using a value of £60/MWh for the unit cost of losses[22] and an annual discount rate of 3.5%. Figure 24 shows the overall net cost of losses (i.e. net-off “Baseline” trajectory) in GB distribution networks under the “Low”

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[22] ENA, 2013. “Reviewing Network Benefits of Smart Meter Message Flows”, EA Technology Ltd report to the Energy Networks Association, 30 Apr 2013.

and "High" trajectories compared against the "Baseline" trajectory for the levels of uptake of LCTs and for the period 2015 – 2030.

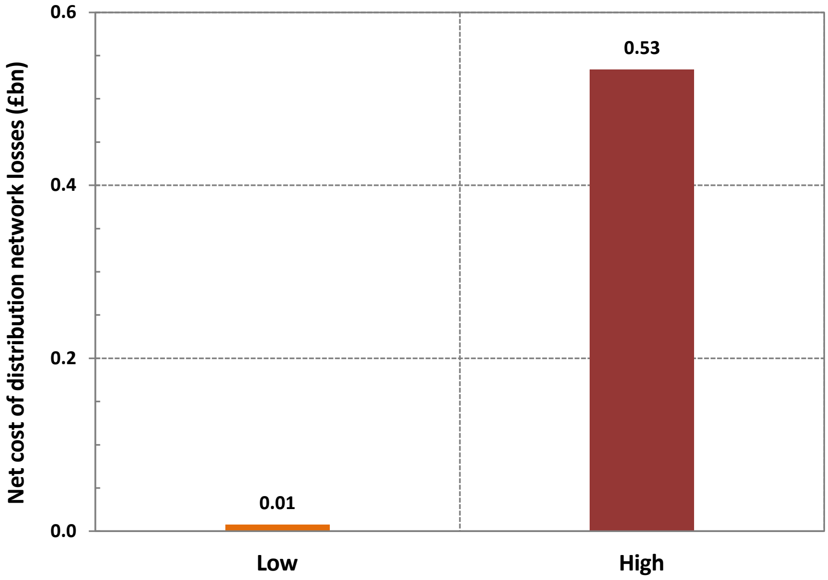
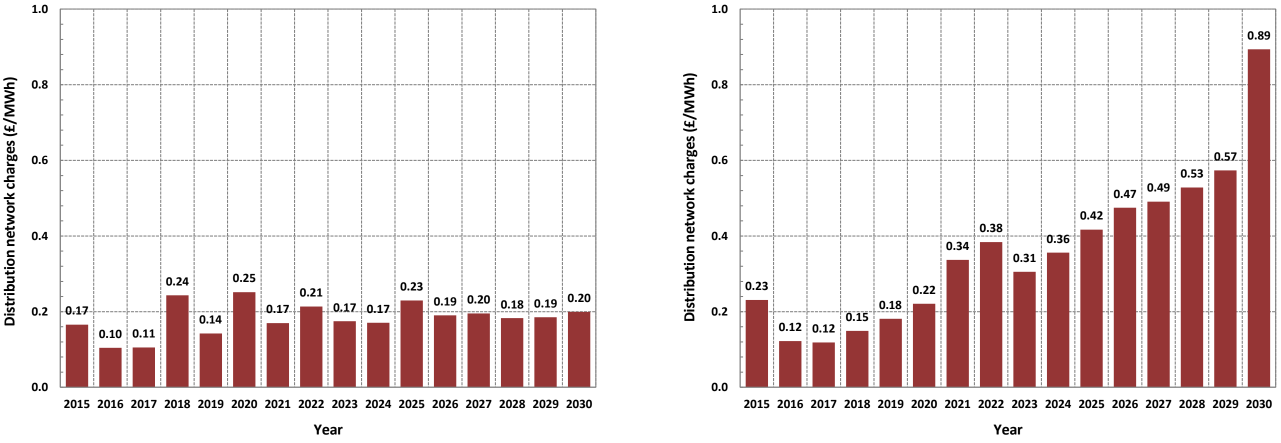


Figure 24: Net cost of losses in distribution networks

It is seen in Figure 24 that the "High" policy trajectory drives a substantial increase on the overall net cost of distribution network losses relative to the "Low" policy trajectory. Overall, the presence of significant levels of uptake of LCTs overbalances the effects that energy efficiency measures may have on demand reduction during the period of analysis, resulting in higher net cost of distribution network losses.

6.5 Distribution network charges

The analysis explores the range of impacts that different uptake levels of LCTs have on distribution network charges. In order to capture a wide range of impacts, the analysis has used the "Low" and "High" trajectories for the uptake levels of LCTs. Thus, Figure 25 provides the distribution network charges for the "Low" and "High" trajectories over the period 2015 – 2030.



(a) "Low" trajectory **(b) "High" trajectory**

Figure 25: Distribution network charges

Figure 25a shows for the "Low" trajectory, characterised by low uptake levels of the LCTs, that the distribution networks charges remain fairly stable over the period of analysis. However, Figure 25b indicates that as the uptake levels of LCTs in distribution network rises as in the “High” trajectory, then the network charges present higher levels of variability over the period of analysis.

In this respect, LCTs are estimated to contribute to a slight increase in Distribution Use of System charges (i.e. DUoS). On average (i.e. period 2015 – 2030), distribution networks charges were found to range from £0.18/MWh in the “Low” to £0.36/MWh in the “High” Trajectory.

6.6 Metrics for distribution network expenditure

This analysis presents three metrics to establish a relationship between distribution network investment expenditure and the uptake level of LCTs. To this objective, the metrics “Number of Interventions per MW of LCTs” and “Currency per Number of Interventions” are considered in the analysis. These metrics have been used by Ofgem to compare the distribution network expenditure projected by different DNO’s in the RIIO-ED1 Business Plans. The Transform Model provides enough information such as the number, type and cost of interventions to quantify such metrics. Furthermore, EA Technology proposes an alternative metric as “Currency per MW of LCT” to provide a clear link between the cost of interventions and uptake levels of LCTs.

The metric “Number of Interventions per MW of LCTs” is attained by simply counting the total number of interventions performed in the distribution network to accommodate LCTs and dividing it by the total uptake levels of all LCTs in MW. Network interventions represent the deployment of solutions and enablers in the network to improve the physical levels of network headroom. The Transform Model selects the most technical and economically efficient set of network interventions and provides it as an output. The total uptake levels of all LCTs in MW is determined from the input trajectories.

The metric “Currency per Number of Interventions” is determined through the division of the overall expenditure required for distribution network development (i.e. costs associated with the deployment of solutions and enablers) by the total number of intervention performed in the distribution network to accommodate LCTs.

The metric “Currency per MW of LCT” is simply the product of the previous two metrics, i.e. “Currency per Number of Interventions” times “Number of Interventions per MW of LCTs”.

Table 9 details the average of the metrics for distribution network investment expenditure in GB for the “High” and “Low” trajectories, over the period 2015 – 2030.

Table 9: Average metrics (over the period 2015 – 2030) for distribution network investment expenditure

Period	“High” policy trajectory			“Low” policy trajectory		
	Number of interventions per MW of LCT	£ per number of interventions	£ per MW of LCT	Number of interventions per MW of LCTs	£ per number of interventions	£ per MW of LCT
2015 – 2030	0.18	119,152	7,547	0.20	31,040	5,103

It is seen in Table 9 that over the period of analysis, the distribution network expenditure ranges on average, from £5.1k/MW of LCT connected in the “Low” trajectory to £7.5k/MW of LCT connected in the “High” trajectory. Alternatively, over the period of analysis, the distribution network expenditure is observed to range on average, from £31k per number of network interventions in the “Low” trajectory to £119k per number of network interventions in the “High” trajectory.

6.7 DNOs’ network expenditure for RIIO-ED1 period

The analysis provides an indication of the levels of expenditure required by DNOs for distribution network reinforcement over the RIIO-ED1 period. EA Technology has interpreted the publicly available initial DNO Business Plans for the RIIO-ED1 period (2015 – 2023). These plans have been submitted to Ofgem and have been assessed.

The DNO Business Plans for LCT related expenditure have been based on DNOs' customised version of the Transform Model which has been run using their own best view of the future uptake of LCTs. It should be noted that DNOs' best view does not necessarily correspond to the published DECC scenarios.

Figure 26 shows the levels of distribution network expenditure required by different GB DNOs to mitigate the impact of LCT connection to the network for RIIO-ED1 period. Given that Figure 26 is based on publicly available information presented by each DNO as part of their initial business plans (submitted in July 2013), it is therefore difficult to ascertain whether each licence has been quantified on a true like-for-like basis.

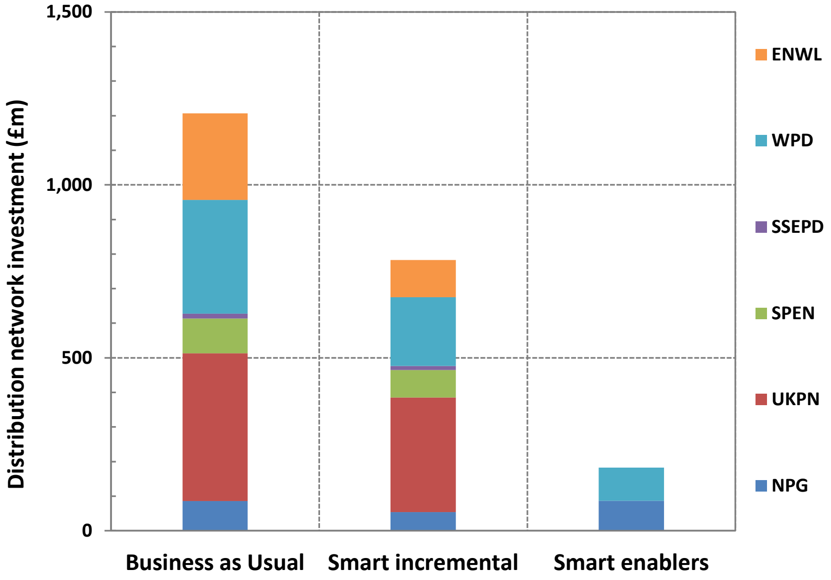


Figure 26: Distribution network expenditure required by DNOs for RIIO-ED1 period

It can be seen in Figure 26 that favouring the deployment of a mixture of conventional and smart solutions is beneficial for GB electricity customers as DNOs network expenditure is estimated to reduce from £1,207m in the business as usual strategy to £966m in the smart strategy. The latter is further disaggregated into £783m in the incremental strategy and £183m in smart enablers.

Figure 26 also shows that some DNOs, such as WPD and NPG, appear to adopt a selective top-down strategy towards network development, by investing ahead of time in enabler technologies and then in network solutions when networks reach their physical headroom limits. It is noted that Ofgem supported WPD's network investment strategy by fast tracking WPD's business plan for RIIO-ED1 period.

6.8 Conclusions

EA Technology has used a sensitivity analysis approach to investigate the impact of key factors on distribution network investment and policy development. The key findings of the analyses can be summarised as follows:

- Smart distribution network investment strategies (i.e. incremental and top-down) that use innovative solutions in conjunction with conventional reinforcement options appear to be more cost effective than using solely conventional solutions (i.e. business as usual).

- Incentivising the deployment of hybrid heat pumps significantly reduces the overall expenditure requirements for distribution network investment compared to non-hybrid heat pumps. The overall distribution network expenditure ranges from £3.3bn with hybrid heat pumps to £6.2bn with non-hybrid heat pumps over the period 2015 – 2030.
- Distributed generation has a relatively low impact on expenditure requirements for the development of distribution networks as solar photovoltaic and wind power technologies generally contribute to offset load growth imposed by other LCTs and also because the contribution of these distributed generation resources towards constraining distribution network headroom is limited.
- The introduction of energy efficiency measures together with a relatively mild uptake of LCTs over the period 2015 – 2020, results in reduced levels of demand which in turn decrease network losses. In the period 2020 – 2030, the rise in the uptake of LCTs and economic growth results in higher demand for energy and consequently network losses.
- The increasing uptake of LCTs overbalances the effects that energy efficiency measures may have on demand reduction over the period of analysis, leading to higher costs attributable to distribution network losses.
- LCTs are estimated to contribute to a slight increase in Distribution Use of System charges (i.e. DUoS) irrespective of government policy. On average (i.e. period 2015 – 2030), LCT related distribution network charges were found to range from £0.18/MWh in the “Low” to £0.36/MWh in the “High” Trajectory.
- The relationship between distribution network investment expenditure and the uptake level of LCTs has been expressed through the metric “Currency per MW of LCT”. Over the period of 2015 – 2030, the distribution network expenditure ranges on average, from £5.1k/MW of LCT connected in the “Low” policy trajectory to £7.5k/MW of LCT connected in the “High” policy trajectory.

7 Summary of key findings

The key findings of the analyses performed by EA Technology are based on the LCTs' trajectories provided by DECC and can be summarised as follows:

- The overall expenditure requirements for LCT related distribution network investment[23] in the period 2015 – 2030 are mainly driven by the electrification of heating and transport sectors. Load technologies such as heat pumps and electric vehicles significantly increase the load on distribution networks. Heat Pumps are estimated to drive 60% of the overall distribution network expenditure related to LCTs whilst electric vehicles drive 38% under DECC's "High" trajectory for all LCTs.
- Generation technologies such as distributed solar photovoltaic and wind have low or no impact respectively, on the overall expenditure requirements for distribution network investment (i.e. total network expenditure for the period 2015 – 2030) when modelled as having equal probability of connecting at various points along a circuit. These LCTs are observed to contribute to offset load growth imposed by the electrification of heating and transport sectors. Distributed solar photovoltaic are estimated to drive 2% of the overall distribution network expenditure. It should be noted that this refers only to generation connected at 33kV and below and only costs that are socialised through DUoS (i.e. not costs associated with large generators that are borne by developers and can be significant).
- Nevertheless, the investment profile for distribution network assets is triggered by different LCTs over time. In the short term, distribution network investment is observed to be driven by distributed solar photovoltaic and distributed wind as the presence of heat pumps and electric vehicles in the network are relatively low. In the long term, the electrification of the heating and transport sectors are estimated to trigger most of the investment requirements for distribution network development.
- The overall network expenditure driven by LCT policy "in place or sufficiently planned" is relatively close to that of a no-policy case (i.e. "Baseline"). Thus, policy "in place or sufficiently planned" initiates the transition process to a low carbon economy of the future, incentivising the deployment of LCTs amongst other measures, without increasing significantly the overall expenditure requirements for distribution network development over the period 2015 – 2030.
- On average over the period 2015 – 2030, LCT policy "in place or sufficiently planned" is estimated to increase the distribution network charges by 3 pence compared to the "Baseline" trajectory. Specifically, the Distribution network Use of System charges (DUoS) increase from £0.16/MWh in the "Baseline" trajectory to £0.19/MWh in the policy "in place or sufficiently planned". This excludes the impact of efficiency measures. Simplified analysis of DECC's 2013 Updated Energy Projections (UEP) for indicative purposes, shows that energy efficiency policies (those in place or sufficiently planned) are likely to more than offset this cost.
- Electricity Market Reform (EMR) and small scale Feed-in Tariffs (FiTs) policy measures have a relatively low impact on expenditure for distribution network investment as the contribution of distributed solar photovoltaic and wind power technologies often has a positive, rather than a negative, impact on network capacity, provided that sufficient demand levels persist to absorb this generation capacity, meaning that its contribution towards constraining distribution network headroom is limited.
- The range of impact of EMR and FiTs policy measures on the expenditure required for investment in distribution network assets is relatively narrow. The overall distribution network expenditure ranges from £0.9bn in the "Low" trajectory to £1bn in the "High" trajectory over the period 2015 – 2030.
- Smart distribution network investment strategies (i.e. incremental and top-down) that use innovative solutions in conjunction with conventional reinforcement options appear to be more cost effective than using solely conventional solutions (i.e. business as usual).

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[23] All prices based on 2013/14 figures.

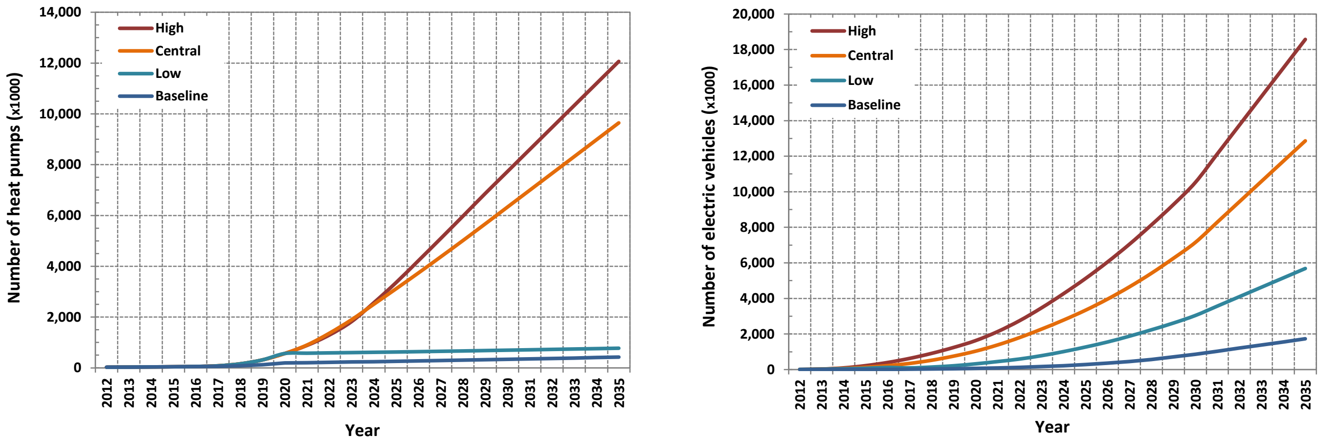
- Incentivising the deployment of hybrid heat pumps significantly reduces the overall expenditure requirements for distribution network investment. The overall distribution network expenditure ranges from £3.3bn with hybrid heat pumps to £6.2bn with non-hybrid heat pumps over the period 2015 – 2030 under DECC's high trajectories.
- The introduction of energy efficiency measures together with a relatively mild uptake of LCTs over the period 2015 – 2020, results in reduced levels of demand which in turn decrease network losses. In the period 2020 – 2030, the rise in the uptake of LCTs and economic growth results in higher demand for energy and consequently network losses. Over the period 2015 – 2030, the effects that energy efficiency measures may have on electricity demand reduction are outweighed by those driven by the increasing presence of LCTs resulting in higher costs attributable to distribution network losses.
- LCTs are estimated to contribute to a slight increase in Distribution Use of System charges (i.e. DUoS). On average (i.e. period 2015 – 2030), distribution networks charges were found to range from £0.18/MWh in the "Low" to £0.36/MWh in the "High" Trajectory. This excludes any offsetting impact from energy efficiency measures.
- The relationship between distribution network investment expenditure and the uptake level of LCTs has been expressed through the metric "Currency per MW of LCT". Over the period of 2015 – 2030, the distribution network expenditure ranges on average, from £5.1k/MW of LCT connected in the "Low" policy trajectory to £7.5k/MW of LCT connected in the "High" policy trajectory.

Appendix 1

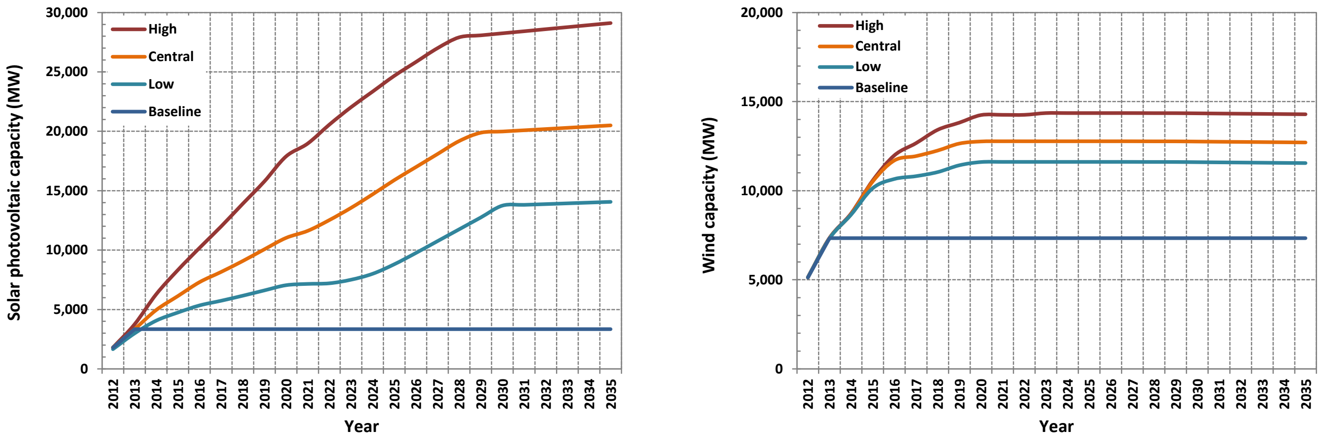
EA Technology's assessments and analyses are based on the detailed application of its proprietary Transform Model that employs a forward look approach to network investment. Thus, the model has been developed to satisfy the headroom requirements at a given point in time (i.e. n, where n is the number of years forward). It has been agreed with DECC, during the scoping phase of the project, that the number of years forward to be used in the analyses would be equal to five.

Since the Transform Model has been set, in this project, to resolve network headroom constraints for a minimum of five years from the time the headroom trigger is reached, an extra five years' worth of data is required (i.e. 2031 – 2035). In this respect, EA Technology has extrapolated DECC's data sets to represent the uptake levels of LCT's during the forward looking period.

Figure 27 shows the three trajectories (i.e. "Low", "Central" and "High") for each LCT over the period of 2012 – 2035.



(a) Heat pumps **(b) Electric vehicles**



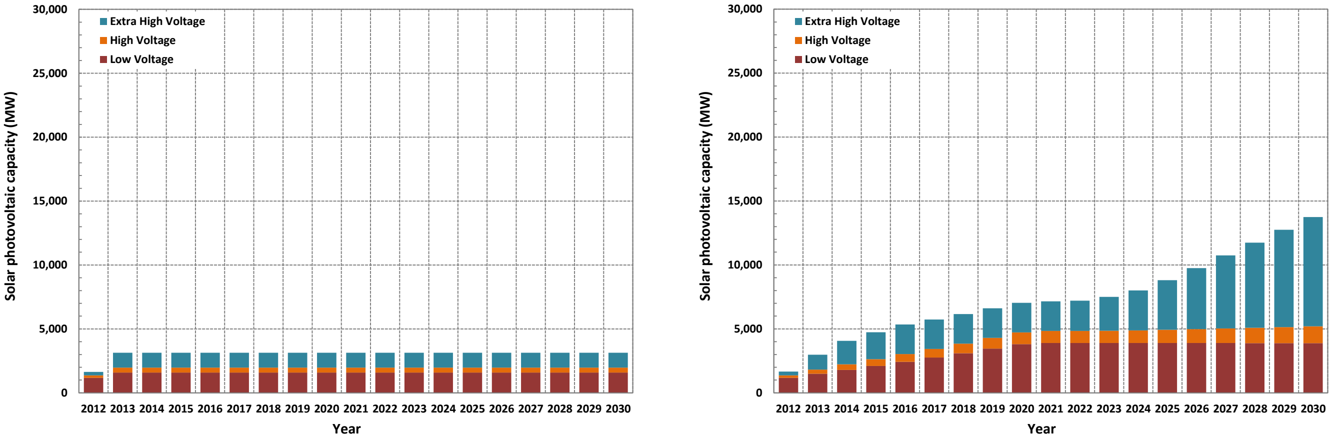
(c) Solar photovoltaics **(d) Wind**

Figure 27: Uptake levels for LCT's – DECC's trajectories 2012-2030; EA Technology's trajectories 2031-2035

Appendix 2

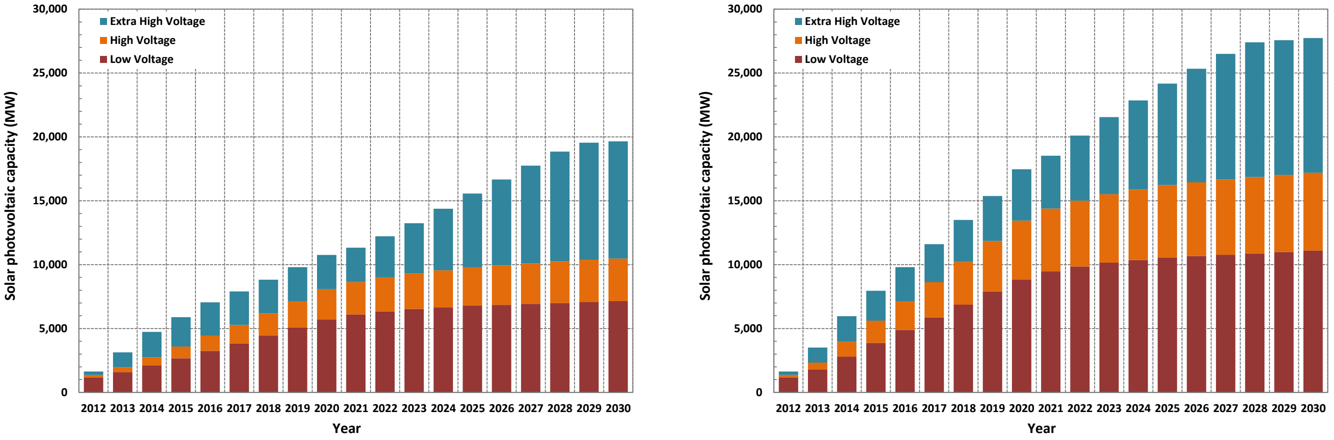
The trajectories for the uptake levels of distributed generation have been disaggregated into the different voltage levels to which they connect in the distribution network. The Transform Model performs this disaggregation process relative to the size of the LCT's uptake level. The apportionment factors used in the disaggregation process has been derived from information receive from the DNOs.

Figure 28 shows the trajectories for the uptake of distributed solar photovoltaic generation per voltage level of the distribution network.



(a) "Baseline" trajectory

(b) "Low" trajectory

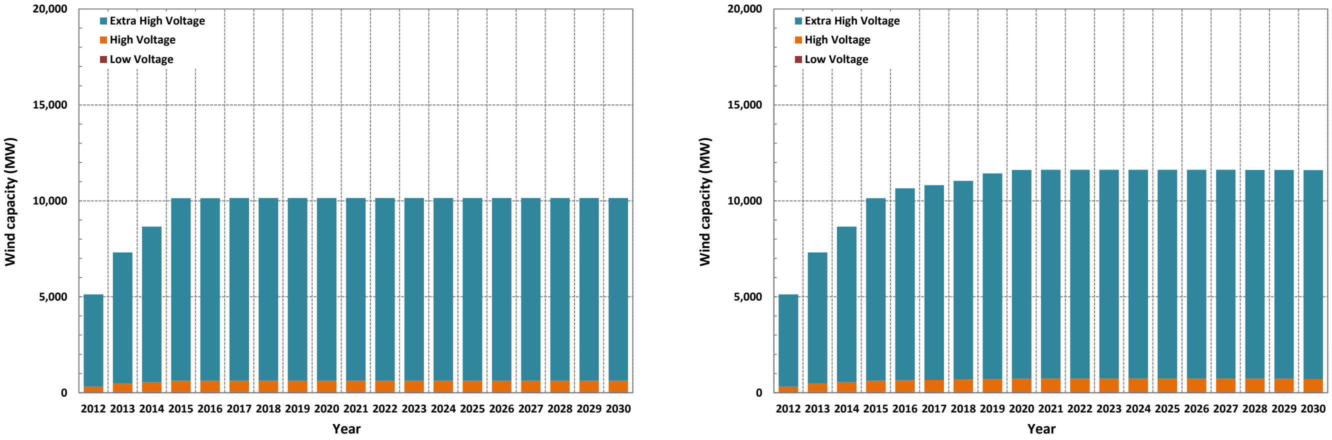


(c) "Central" trajectory

(d) "High" trajectory

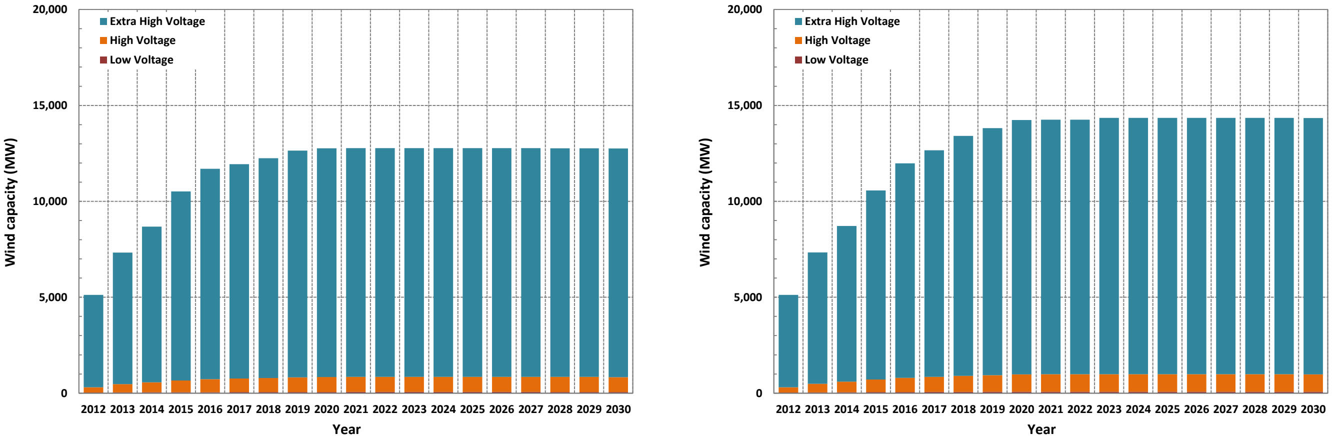
Figure 28: Uptake levels for distributed solar photovoltaic per voltage level

Figure 29 shows the trajectories for the uptake of distributed wind generation per voltage level of the distribution network.



(a) “Baseline” trajectory

(b) “Low” trajectory



(c) “Central” trajectory

(d) “High” trajectory

Figure 29: Uptake levels for distributed wind per voltage level

Appendix 3

The trajectories (i.e. “Low”, “Central” and “High”) characterising the uptake levels of each LCT, (i.e. HP, EV, PV and Wind) have been combined in a specific manner to address the project questions as in DECC’s Research Project Specification. Table 10 presents an overview of the main trajectory combinations considered in the report. It is noted that other combinations were considered where appropriate to quality assure some of the analyses undertaken in the report.

Table 10: Main combinations of policy trajectories

Report section	Analysis	Heat pumps	Electric vehicles	Solar photovoltaic	Wind
4 LCT driven distribution network investment	4.3 Contribution of LCTs to distribution network investment	High	High	High	High
		Baseline	High	High	High
		High	Baseline	High	High
		High	High	Baseline	High
		High	High	High	Baseline
5 Policy driven distribution network investment	5.1 Policy “in place or sufficiently planned”	Low	Low	Central	Central
		Baseline	Baseline	Baseline	Baseline
	5.1.2 DECC’s Energy and Emissions Projections	Reference Scenario	Reference Scenario	Reference Scenario	Reference Scenario
		Baseline Scenario	Baseline Scenario	Baseline Scenario	Baseline Scenario
	5.2 Electricity Market Reform	Baseline	Baseline	High	High
		Baseline	Baseline	Central	Central
		Baseline	Baseline	Low	Low
		Baseline	Baseline	Baseline	Baseline
6 Sensitivity and further analyses	6.1 Network development strategy	High	High	High	High
		High	High	High	High
		High	High	High	High
	6.2 Technology type of heat pumps	High	High	High	High
		High	High	High	High
	6.3 Distributed generation	High	High	High	High
		High	High	Baseline(-flat)	Baseline(-flat)
	6.4 Distribution network losses	High	High	High	High
		Low	Low	Low	Low
	6.5 Distribution network charges	High	High	High	High
		Low	Low	Low	Low
	6.6 Metrics for distribution network expenditure	High	High	High	High
		Low	Low	Low	Low

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